DEPARTMENT OF DEFENSE APPROPRIATIONS FOR FISCAL YEAR 2015

WEDNESDAY, MAY 14, 2014

U.S. SENATE,
SUBCOMMITTEE OF THE COMMITTEE ON APPROPRIATIONS,
Washington, DC.

The subcommittee met at 9:59 a.m., in room SD–192, Dirksen Senate Office Building, Hon. Richard J. Durbin (chairman) presiding.

Present: Senators Durbin, Cochran, Shelby, Collins, and Murkowski.

DEPARTMENT OF DEFENSE

DEFENSE RESEARCH AND INNOVATION

STATEMENT OF ALAN SHAFFER, ASSISTANT SECRETARY OF DEFENSE FOR RESEARCH AND ENGINEERING

OPENING STATEMENT OF SENATOR RICHARD J. DURBIN

Senator DURBIN. Good morning. Today the subcommittee meets to receive testimony on the fiscal year 2015 budget request for science and technology (S&T) funding for the Department of Defense (DOD), the military services, and defense medical research programs.

I want to welcome our witnesses: Mr. Alan Shaffer, Acting Assistant Secretary of Defense for Development, Research and Engineering for the Department of Defense; Dr. Arati Prabhakar, Director of DARPA (Defense Advanced Research Projects Agency); Dr. Terry Rauch, Director of Defense Medical Research and Development Program with the Office of Force Health Protection and Readiness Programs; Ms. Mary Miller, Deputy Assistant Secretary of the Army for Research and Technology; Dr. David Walker, Deputy Assistant Secretary of the Air Force for Science, Technology, and Engineering; and Rear Admiral Matthew Klunder, Chief of Naval Research.

This year's budget request for science and technology funding among the Department and the services is $11.5 billion out of a total research and development (R&D) request of $63.5 billion. In fiscal year 2015, the overall R&D budget increases $569 million. However, this growth is not reflected in science and technology research. Basic research is down by $150 million across the Department and the services, overall science and technology reduced by

almost $500 million. I hope our witnesses can provide some insight into the choices that need to be made with these numbers.

Science and technology investments have led to stunning advancements on behalf of our military men and women and the Nation. From DARPA's early investments that led to the Internet to the Department's development of one of the most widely used drugs to fight breast cancer, these investments are critical in keeping the U.S. at the top when it comes to new ideas and new innovation.

I am worried that the budget decisions we have made over the past several years may be putting this leadership at risk.

Two weeks ago, the full Appropriations Committee held a hearing examining Federal investments that drive innovation. During that hearing, Dr. Collins from NIH (National Institutes of Health) presented a slide that was extremely worrisome. I have provided a copy to our members and our witnesses. It shows the relative decline in U.S. Federal investment in biomedical research and compares this with the research of our allies and competitors who are significantly increasing their biomedical investments.

To address this research deficit, I have introduced a bill. It is called the America Cures Act. The bill will make stable investments in biomedical research at a rate of inflation plus 5 percent. This funding would provide stability to NIH, CDC (Centers for Disease Control and Prevention), the Department of Defense, and the Department of Veterans Affairs (VA) so they can plan and execute their research programs with certainty.

But it is not just our biomedical edge that is at risk. Lagging investments in science and technology risk sacrificing America's technological edge to our enemies. It also poses significant challenges to sustaining America's talented pool of engineers and Ph.D.'s in computing, materials science, and many other fields.

Advances in these fields are not just for our national security. They find their way into high-tech components in almost every household in America. Right now, we are carrying around in our pockets a GPS device. This was designed and originally discovered with the launch of Sputnik, a satellite in 1957. They tried to track that Russian satellite and the beep that it was emitting they were able to determine how they could position themselves on earth and identify that location based on where the satellite was. Now we carry it around in our pockets and do not think twice about it. That is the kind of thing where what looks like pure defense research turns out to be research of great value to us in many other areas. The gyroscopes in our cell phones, lithium batteries—the list goes on and on—originating in the Department of Defense.

Ignorance is no shelter or refuge. I think back to that same era when Congress decided to create the National Defense Education Act in 1958, the first time in the history of the United States that we gave scholarships to anyone who was not a veteran. And the reason was we were scared of the Soviet Union and their satellites. Our first line of defense was to educate America. Let us get ready to fight this battle with people who are well educated and trained and can not only defend us but make us a stronger Nation and a stronger economy.

Now look where we are today. We are backing off of our commitment to research, science, and technology. What does that say

about our future? How do we explain that to our kids? Extremely shortsighted. That is why we are having this hearing.

I look forward to your testimony and note your full statements will be part of the record.

PREPARED STATEMENT

Before I turn to the vice chairman of the subcommittee, Senator Thad Cochran, Senator Collins submitted a statement to be included in the record.

[The statement follows:]

PREPARED STATEMENT OF SENATOR SUSAN M. COLLINS

Thank you, Chairman Durbin, for holding this important hearing on Defense Research and Innovation.

Research and innovation reflect the American spirit of ingenuity. Our national labs, colleges and universities (including the University of Maine), private sector entrepreneurs, small businesses, investors, and countless others play a significant role in spurring innovation, and we should support policies that encourage such inventiveness and allow the United States to remain a leader in creating cutting edge technologies. I would note that one area where we can do more to encourage innovation is increasing investment in small businesses that are developing technologies that contribute to the national defense and reducing the barriers they face in contracting with the Federal Government.

The Rapid Innovation Program, which transitions small business technologies into Defense Acquisition Programs, is a great example of how the Defense Department can assist small business innovation. MARCOR, located in Boothbay, Maine, is just one of the more than 360 companies since 2011 that have received contracts worth nearly $900 million in research and development (R&D) investment.

Another program that makes it easier for small businesses to apply their innovation to our national security is through the Procurement Technical Assistance Program, which has six locations in Maine. This program helps small businesses seeking to do business with the Federal Government. The Procurement Technical Assistance Centers plays a critical role in facilitating matches by connecting small businesses with prime contractors and Federal agencies, and by helping them through the contracting process from start to finish.

A strong partnership between the public and private sectors is vital to getting the most out of our R&D dollars, and as such this partnership is vital to our national security as well.

I look forward to your testimony today.

Senator DURBIN. Senator Cochran.

STATEMENT OF SENATOR THAD COCHRAN

Senator COCHRAN. Mr. Chairman, I am pleased to join you in welcoming our panel of witnesses at the hearing this morning. We appreciate the work that you do in identifying areas of emphasis where we want to be sure that we appropriate the adequate sum of dollars that are needed to take advantage of the emerging technology in our society as it relates to our national defense and the security of American citizens. We thank you for being here this morning to share your thoughts and observations about these issues.

Thank you.

Senator DURBIN. Thank you very much, Senator Cochran.

We are going to ask the witnesses to each give a brief opening statement before questions, and of course, their written statements will be made part of the record.

Mr. Shaffer, why do you not start?

SUMMARY STATEMENT OF ALAN SHAFFER

Mr. SHAFFER. Chairman Durbin, Vice Chairman Cochran, members of the committee, I am pleased to come before you today to testify about the state of the Department of Defense science and technology program. I am proud to be here representing the roughly 100,000 scientists and engineers in the Department's workforce, a workforce that has provided, as you said, Mr. Senator, remarkable achievements in the past but one that is now showing the early stages of stress due to downsizing and the combined sequester, furlough, and Government shutdown challenges of the last year. These affected the health of our workforce and their programs they execute in ways we are just beginning to understand. We have begun to address these challenges, but they remain a concern to us.

As you said, sir, the 2015 S&T budget request is down about 5 percent to $11.5 billion compared to the fiscal year 2014 $12 billion request. While the DOD tries to balance our overall program, there are factors that led Secretary Hagel to conclude in his February 24 budget rollout that we are entering an era where American dominance on the seas, in the skies, and in space can no longer be taken for granted.

The Department is in the third year of a protracted overall budget drawdown and, as highlighted by Secretary Hagel, there are three major areas that compromise the Department's budget: force size, readiness, and modernization.

The current budget is driving a force reduction, but this reduction will take several years to yield savings. In the fiscal year 2015 budget, readiness and/or modernization will pay a larger percentage of the overall Department bill.

To address the challenges, we needed to examine the strategy we are using to focus the S&T investment on high priority areas. From that review emerged a strategy for investment. The Department invests in science and technology for one of three reasons.

The first is to mitigate new and emerging threat capabilities, and we see a significant need in the areas of electronic warfare, cyber, counter-weapons of mass destruction, and preserving space capabilities.

The second reason we invest in science and technology is to affordably enable new or extended capabilities in existing military systems and our future systems. We see a significant need in growing our Department's system engineering, modeling and simulation and prototyping.

The third reason we invest in science and technology is to develop technology surprise. We want to keep potential adversaries on their heels. We see significant need in areas such as autonomy, human systems, quantum sensing, and big data.

While there are challenges, the Department continues to perform. I would like to highlight several areas.

First, advances in understanding and treating such things as traumatic brain injury. In addition, to the DARPA BRAIN (Brain Research through Advancing Innovative Neurotechnologies) Initiative, the Department has developed some successful technologies in this area in both the medical research program and in our Army's research program. The combination of DARPA's small blast gauge

to measure the blast over-pressures and acceleration of the head, coupled with the Defense Health Programs' advances in therapeutics and photonic medicine, provides promise to allow us to treat TBI (traumatic brain injury) more quickly and effectively. The photonics advancements, I will tell you, show real potential. Growing out of that program, researchers have discovered that intense light outside the skull prevents brain tissue decay after a TBI-inducing event. The treatment is in clinical trials.

The Air Force X–51 WaveRider hypersonic demonstration was the second successful demonstration of powered scramjet technology demonstrating that we are getting close to developing a full hypersonic system. No one else in the world has done this.

The Navy is making dramatic progress on high energy laser systems and is deploying a 30-kilowatt electric laser on the USS *Ponce* this summer. If successful, this will be the first operational deployment of a directed energy system.

PREPARED STATEMENT

The Army is forging the next generation of military helicopters with their joint multirole technology demonstrator, a program currently in design phase with four vendors leading to the next generation of military-relevant helicopters.

These successes highlight that in spite of a difficult year and in spite of difficult budget pressures, the DOD S&T program continues to produce capability for our future force. With your continued support, I am confident we will continue to do so in the future.

[The statement follows:]

PREPARED STATEMENT OF ALAN R. SHAFFER

Chairman Durbin, Vice Chairman Cochran, members of the committee: I am pleased to come before you today to testify about the state of the Department of Defense's science and technology (S&T) program. I am proud to be here representing the roughly 100,000 scientists and engineers in the science and engineering (S&E) workforce, a workforce that has had remarkable achievements in the past, but is now a workforce showing the early stages of stress due to downsizing and the budget challenges of the last year. This past year has been unlike previous years in our community; the collective impact of the sequester-forced civilian furlough and program curtailment, the October 2013 Government shutdown, and the indirect impacts of the sequester, such as restrictions on our young scientists and engineers attending technical conferences, has impacted the health of our workforce and the programs they execute in ways that we are just beginning to understand. We have begun to address these challenges but they remain a concern for us.

INTRODUCTION

The fiscal year 2015 budget request for science and technology (S&T)[1] is relatively stable, when compared to the overall DOD top line[2] and modernization accounts. The DOD fiscal year 2015 S&T request is $11.51 billion, compared to an fiscal year 2014 appropriation of $12.01 billion. This request represents a 4.1 percent decrease (5.8 percent in real buying power) in the Department's S&T compared to Research, Development, Test and Evaluation (RDT&E) account that was virtually unchanged. While we continue to execute a balanced program overall, there are factors that led Secretary Hagel to conclude in his February 24, 2014 fiscal year 2015

[1] Science and Technology is defined as program 6, budget activities 1, 2, and 3; frequently called 6.1, 6.2, and 6.3 (basic research, applied research, and advanced technology development); Research and Engineering adds Advanced Capability Development and Prototyping (6.4).

[2] Top line refers to the total funds appropriated by Congress to include "supplemental" or Oversees Contingency Operations funds.

budget rollout that "we are entering an era where American dominance on the seas, in the skies, and in space can no longer be taken for granted".[3]

Simultaneous with the challenges of balancing a reduced budget and continuing to engage the total defense workforce in meaningful research and engineering (R&E), the capability challenges to our R&E program are also increasing. This is attributable to changes in the global S&T landscape and the acceleration globally of development of advanced military capabilities that could impact the superiority of U.S. systems. The convergence of declining budgets, in real terms, and increased risk is not a comfortable place to be. However, as I will highlight in the latter sections of my statement, the Department has begun to reshape the focus of our technical programs to address some of our new challenges. We are also beginning to shift our programs to better position the Department to meet our national security challenges. Finally, we have some areas where we need your help in order to be successful executing our fiscal year 2015 budget. I will cover these areas at the end of my statement.

FISCAL YEAR 2015 PRESIDENT'S BUDGET REQUEST

The current fiscal environment presents significant challenges to the DOD budget. The Department is in the third year of a protracted overall topline and RDT&E budget drawdown. As highlighted by Secretary Hagel, there are three major areas that comprise the Department's budget: force size, readiness, and modernization. The current budget is driving a force reduction, but this reduction will take several years to yield significant savings. In the fiscal year 2015 budget, readiness and/or modernization will pay a larger percentage of the "bill". As a former airman who entered service in the 1970s, I am very well aware of what happens when savings are gleaned from readiness—the hollow force is not acceptable. Over the next several years of the budget we expect modernization accounts (Procurement and RDT&E) to pay a large portion of the Department's fiscal reduction bill. At the same time, Secretary Hagel's strategy is to protect advanced technologies and capabilities. The fiscal year 2015 budget must balance all of these drivers; we believe we have done well, but do acknowledge there is increased risk.

The last several budgets have been characterized by instability and rapid decline of the modernization accounts. The fiscal year 2013 sequestration reduced all accounts by 8.7 percent; for S&T, this amounted to a loss of about $1 billion. The December 2013 Bipartisan Budget Act increased the discretionary caps in fiscal year 2014 and fiscal year 2015 to provide some relief, but less in fiscal year 2015 than fiscal year 2014. From fiscal year 2013 to 2015, the S&T program operated with reductions of $1.4 billion compared to what had been planned in the fiscal year 2013 budget.

One of the key points for S&T of the fiscal year 2015 budget is a shift in focus at the macro scale from basic research to advanced technology development and a shift from the Services to DARPA to develop advanced capabilities. In fiscal year 2015, we funded DARPA at the same level, after inflation, as was planned in fiscal year 2014 PBR. These numbers are shown in Tables 1 and 2.

	FY 2014 appropriated ($M)	PBR 2015 (FY 14 CY $M)	% Real change from FY 2014 appropriated (FY 14 CY $)
Basic Research (BA 1)	2,167	2,018 (1,982)	−8.55%
Applied Research (BA 2)	4,641	4,457 (4,378)	−5.66%
Advanced Technology Development (BA 3)	5,201	5,040 (4,951)	−4.81%
DOD S&T	12,009	11,515 (11,311)	−5.81%
Advanced Component Development and Prototypes (BA 4)	11,635	12,334 (12,116)	4.14%
DOD R&E (BAs 1–4)	23,644	23,849 (23,427)	−0.92%
DOD Topline	496,000	495,604 (486,841)	−1.85%

Table 1—Defense Budget for Science &Technology; Research & Engineering; and DOD Top Line Budget (FY 2014 Appropriated and PBR 2015).

[3] Remarks by Secretary Hagel on the fiscal year 2015 budget preview in the Pentagon Briefing Room on 24 February 2014.

	FY 2014 appropriated ($M)	PBR 2015 (FY 14 CY $M)		% Real change from FY 2014 appropriated (FY 14 CY $)
Army	2,455	2,205	(2,166)	−11.77%
Navy	2,102	1,992	(1,957)	−6.91%
Air Force	2,308	2,129	(2,091)	−9.39%
DARPA	2,707	2,843	(2,793)	3.17%
Missile Defense Agency (MDA)	255	176	(173)	−32.20%
Defense Threat Reduction Agency (DTRA)	476	473	(465)	−2.39%
Chem Bio Defense Program (CBDP)	393	407	(400)	1.73%
Other Defense Agencies	1,313	1,290	(1,267)	−3.49%
DOD S&T	12,009	11,515	(11,311)	−5.81%

Table 2—Service and Agencies S&T Budgets (FY 2014 Appropriated and PBR 2015)

Research and Development is Not a Variable Cost

Over the past decade, the R&D accounts have been quite variable, but this counters one of the key tenets of R&D investment made by the Honorable Frank Kendall in discussing the fiscal year 2015 budget. There has been a tendency in the past to reduce research and development more or less proportionately to other budget reductions. This tendency, if acted upon, can be detrimental because research and development costs are not directly related to the size of our force or the size of the inventory we intend to support. The cost of developing a new weapons system is the same no matter how many units are produced. In a recent speech, Secretary Kendall explained the invariant nature of research and development this way:

> R&D is not a variable cost. R&D drives our rate of modernization. It has nothing to do with the size of the force structure. So, when you cut R&D, you are cutting your ability to modernize on a certain time scale, period—no matter how big your force structure is.[4]

If we don't do the research and development for a new system than the number of systems of that type we will have is zero. It is not variable.

Secretary Kendall said it this way:

> [T]he investments we're making now in technology are going to give us the forces that we're going to have in the future. The forces we have now came out of investments that were made, to some extent, in the 80s and 90s . . . if you give up the time it takes for lead time to get . . . a capability, you are not going to get that back.[5]

There is another trend impacting the Department's ability to deliver advanced capabilities. Recent data from the Nation Science Foundation shows an upward trend in industry R&D spending compared to a downward trend in Federal Government R&D spending (Figure 1). Industry in the United States performs roughly 70 percent of the Nation's R&D with the Federal Government and academia making up the remaining 30 percent. Figure 1 also shows the dependence of academic researchers on Federal Government funding, as noted by the National Science Board:

Most of U.S. basic research is conducted at universities and colleges and funded by the Federal Government. However, the largest share of U.S. total R&D is development, which is largely performed by the business sector. The business sector also performs the majority of applied research.[6]

This implies that DOD needs to be more cognizant of industry R&D as part of our overall capability development and remain sensitive to the importance of federally funded academic research. We continue to push in these areas through our continued support of the university research portfolio and our recent emphasis on Independent Research and Development (IR&D).

[4] Honorable Frank Kendall presentation to McAleese/Credit Suisse fiscal year 2015 Defense Programs Conference on 25 February 2014.

[5] Kendall, 25 February 2014.

[6] National Science Board. 2014. Science and Engineering Indicators 2014. Arlington VA: National Science Foundation (NSB 14–01).

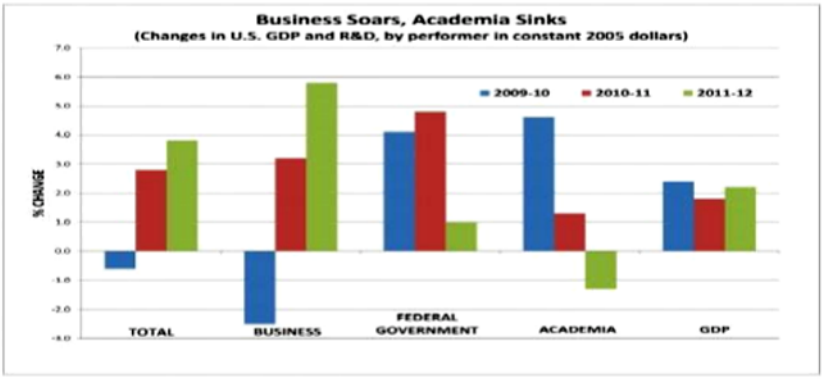

FIGURE 1—CHANGES IN US GDP AND R&D BY PERFORMER [7]

SCIENCE AND ENGINEERING WORKFORCE

The Department's scientist and engineering (S&E) workforce consists of in–house labs, engineering centers, test ranges, acquisition program offices and so forth, and is augmented by our partners in the federally funded research and development centers (FFRDCs) and University Affiliated Research Centers (UARCs). The talented scientists and engineers working within these organizations form the foundation of the Department's technology base and are responsible for conceiving and executing programs from basic research through demilitarization of weapon systems. The technical health of this workforce is a priority for me and the Department.

Our in-house labs have been designated by Congress as Science & Technology Reinvention Laboratories (STRL) providing the directors of these facilities special authorities to manage their workforce via pay-for-performance personnel systems. Each director is granted flexibility to create workforce policies unique to his/her lab with new personnel initiatives being transferable to other STRLs if proven to be effective in the hiring, retention and training of S&Es. Each year my office works with the Services and their labs to ensure they have the authorities our lab directors need. Recent accomplishments include direct hiring authority for bachelors, masters and doctoral level graduates, increase in the number of technical senior executive billets, and authority for lab directors to manage their workforce based upon available budgets.

Data from the Strategic Human Capital Workforce Plan published in September 2013 indicates that our lab workforce is getting older. From 2011 to 2013, the average age of our scientists and engineers in our labs has grown from 45.6 years to 45.7 years for scientists and from 43.2 years to 43.9 years for our engineers. Although the change seems minimal over the past 2 years, it reverses the trend over the past decade when we had been driving the average age down. Data from the Science and Technology Functional Community indicate that the combination of fewer new hires and retirement-eligible employees working longer both contribute to the increase in average age. In 2013, there were only 731 new hires in the S&T Functional Community, whereas in 2010 there were 1,884. In 2010, retiring workers were retirement-eligible for an average of only 4.1 years. From 2011–2013, that average grew to 4.5 years. The trend indicates that we may not be replacing our seasoned employees with enough young scientists and engineers who will shape our future. This could be an indicator of older employees working longer because of a down economy or it could be an indicator that we are not hiring or retaining enough young scientists and engineers.

Although anecdotal, we are seeing a trend in why younger workers may be leaving. We saw a number of young scientists and engineers leave in 2013, early in their career. In conducting exit interviews, our laboratory directors reported that these young workers consistently cited travel and conference restrictions, as well as perceived instability of a long term career as motivating factors for their departure.

[7] Science magazine. 13 January 2014. Retrieved from http://news.sciencemag.org.

This information, although anecdotal, is of concern; consequently, we are attempting to gather data to see if we can discern a definite signal.

Another area of significant Department and national interest is building a robust science and engineering workforce through various Science, Technology, Engineering, and Mathematics (STEM) initiatives. My office recently created the STEM Executive Board who has the authority and continues to provide strategic leadership for the Department's STEM initiatives.

Significant change to the Federal portfolio of STEM programs has occurred over the past year. In response to the requirements of the America Competes Reauthorization Act of 2010, Federal STEM-education programs were reorganized with the goals of greater coherence, efficiency, ease of evaluation, and focus on the highest priorities. This resulted in the Federal STEM Education 5-Year Strategic Plan designating the Smithsonian, Department of Education and National Science Foundation as lead agencies in implementing this plan. The DOD STEM Strategic plan is aligned with the Federal plan to achieve Federal and Departmental STEM education goals.

We are also developing Department-wide guidance on STEM program evaluation, coordinating within the Department and across the Federal Government to improve effectiveness and efficiencies in these investments in future workforce needs. A DOD STEM Annual Report, expected to be delivered in fiscal year 2015 based on fiscal year 2014 data, will communicate the activities and results in achieving Departmental goals.

In summary, budget constraints, furloughs, and conference and travel restrictions have contributed to a drain on our most valuable resource—people. To replace our losses and rebuild our workforce for the future, we are working on bringing stability back to our S&E programs, give our people challenging while enriching environments in which to work.

CHALLENGES TO MAINTAINING TECHNOLOGICAL SUPERIORITY

The United States has relied on a DOD that has had technological superiority for the better part of the post-World War II era. There are factors that are converging such that the DOD maintaining technological superiority is now being challenged. These challenges come from both changes in the way technology matures and in advanced capabilities being developed in the rest of the world. The Department is emerging from over a decade of focusing on countering terrorism and insurgency. While the challenges of counter terrorism remain, new national security challenges are emerging. Other nations are developing advanced capabilities in areas such as: cyber operations, advanced electronic warfare, proliferation of ballistic missiles for strategic and tactical intent, contested space, networked integrated air defenses, and a host of other capabilities stressing the Department's capability advantages. The Department's S&T program is being re-vectored to meet these new challenges. In addition, the Department is shifting to a focus on the Asia-Pacific region, a region with unique and challenging geographic and cultural features. Most notably, the geographic extent of the Asia Pacific region adds new challenges in terms of fuel efficiency and logistics.

In short, the Department and Nation are at a strategic crossroads—the funds available to the Department (and national security infrastructure in general) are decreasing, while the complexity and depth of the national security challenges are growing. The world we live in is an uncertain place. Secretary Hagel said it best in his recent roll out of the fiscal year 2015 budget:

> The development and proliferation of more advanced military technologies by other nations that means that we are entering an era where American dominance on the seas, in the skies, and in space can no longer be taken for granted.[8]

Secretary Hagel went on to say:

> To fulfill this strategy DOD will continue to shift its operational focus and forces to the Asia-Pacific, sustain commitments to key allies and partners in the Middle East and Europe, maintain engagement in other regions, and continue to aggressively pursue global terrorist networks.[9]

Global Changes in S&T Impact Technology Development.—The nature of the international technology landscape is much different than it was even 20 years ago in two fundamental ways:

---

[8] Remarks by Secretary Hagel on the fiscal year 2015 budget preview in the Pentagon Briefing Room on 24 February 2014.

[9] Hagel, 24 February 2014.

—Many technologies of importance to the Department's capability developments are driven by the commercial sector, and have become a global commodity.
—The pace of maturation of technology is accelerating; that is, technology maturation occurs on a more rapid scale than in the past.

Our DOD S&T community needs to identify areas where technology has become a global commodity and not expend resources working to develop the same capability. We must track global technology developments, harness them and apply the technology to our needs. This year, we have initiated a project at the Defense Technical Information Center to improve our ability understand global technology development, and are in pilot phase to use automated tools to assess technology advances.

We already know that industry drives most microelectronics and semiconductors development; older infrared focal planes, routine communications, computers. The technology coming from these sectors is sufficient to meet most DOD capability needs. The DOD should be an adopter, not a leader in these areas while addressing the unique security concerns of these technologies used in our military, cyber and IT systems. The DOD should focus our research in technology integration or in developing technologies into products at performance levels beyond those commercially available or planned. Examples would include electronic travelling wave tubes (led by Naval Research Lab), which provide higher frequency and higher power output than is needed in commercial applications; and infra-red (IR) "super lattice" semiconductors (led by the Army's Night Vision Laboratory), which give high enough resolution in IR to make "movies" out of simple data and images. The DOD should monitor and apply these technologies to meet our needs.

At the same time, we know that the time to mature many technologies is decreasing. We have seen the time from invention to market penetration decrease by a factor of two over the past half century. Consequently, I would like to cite comments made by Mr. Frank Kendall, Under Secretary of Defense for Acquisition, Technology, and Logistics, who states that one of the key factors to maintaining technological superiority is to maintain a steady investment in technology.

> The effects of time (lost) cannot be reversed. It is well understood in the R&D community, and most particularly in the S&T community, that the investments we make today may not result in capability for a generation. It takes upwards of 5, 10, even 20 years to develop a new system, test it, and put it into production. By taking higher risks and accepting inefficiencies and higher costs we can reduce the "time to market" of new weapon systems; in fact, we have reduced this time . . . with reforms put in place in recent years.

Even during World War II we fought with the systems that had been in development for years before the war began. We can shorten, but not eliminate the time required to field new cutting edge weapons systems. But one thing is for sure, if we do not make R&D investments today, we will not have the capability in the future.

Capability Changes to DOD Technology Superiority.—More significant than the changes in how technology is developed and delivered globally are changes in military capabilities being developed by other nations.

I will cite just one example; there are many more. The convergence of advanced digital signals and computer processing has given rise to proliferation of a new class of system—the digital radio frequency memory (DRFM) jammer. DRFM jammers are fairly inexpensive electronic systems that ingest the radar (or communications) signal, analyze the digital waveform, and then generate random signals, with the same waveform, back to the transmitting radar receiver. The result is the radar system sees a large number of "electronic" targets. If the U.S. employed conventional weapons systems using the traditional methods, we could shoot at or chase a lot of false targets. The consequence is that the U.S. needs to develop a counter to DRFM jammers.

The convergence of computer processing, digital signal processing, digital electronics, optical fibers, and precise timekeeping are giving rise to inexpensive enablers that can improve the ability to counter conventional weapons platforms. We are starting to see other nations advance technologies to counter U.S. overmatch by combining the components listed above to enhance capabilities in electronic warfare, longer range air-to-air missiles, radars operating in non-conventional bandwidths, counter-space capabilities, longer range and more accurate ballistic and cruise missiles, improved undersea warfare capabilities, as well as cyber and information operations. We see these types of new capabilities emerging from many countries; to include China, Iran, Russia and North Korea. This has led to a situation where, in the next 5 to 10 years, U.S. superiority in many warfare domains

will be at risk. Accordingly, the following section highlights some of the areas where we are watching.

Proliferation of Weapons of Mass Destruction (WMD).—The 2013 National Security Interests published by the Chairman of the Joint Chiefs of Staff lists as the top priority interest "Survival of the Homeland". The one existential threat to the United States comes from Weapons of Mass Destruction. Traditionally, WMD has included nuclear, chemical and biological weapons and their delivery systems. The emergence of new countries with nuclear ambitions, such as North Korea and Iran, make today's world much more dangerous. Chemical and biological weapons, used in both World Wars, have been resurgent in the past two decades. Perhaps the gravest danger for the United States and the rest of the world is the possibility of WMD falling into the hands of terrorist groups and other groups in the midst of instability. We must continue our vigilance in this area and continue to develop ways to deal with their use.

The United States is currently rebalancing to the Asia Pacific region. As we do so, the Department is faced with a host of new challenges. I will discuss some of the challenges over the next several paragraphs.

Vulnerability of the U.S. Surface Fleet and Forward Bases in the Western Pacific.—U.S. Navy ships and Western Pacific bases are vulnerable to missile strikes from ballistic and cruise missiles already in the inventory. China has prioritized land-based ballistic and cruise missile programs to extend their strike warfare capabilities further from its borders. Chinese military analysts have concluded that logistics and power projection are potential vulnerabilities in modern warfare, given the requirements for precision in coordinating transportation, communications, and logistics networks. China is fielding an array of conventionally armed ballistic missiles, ground- and air-launched land-attack cruise missiles, special operations forces, and cyber-warfare capabilities to hold targets at risk throughout the region. The most mature theater missiles are the DF–21 C/D, which both have 1,500 km radius. They are also developing a longer range missile that would be able to strike as far as Guam. These ballistic missiles are coupled with advanced cruise missiles that could threaten any surface warfare fleet by 2020.

The People's Liberation Army (PLA) Navy has the largest force of major combatants, submarines, and amphibious warfare ships in Asia. China's naval forces include some 79 principal surface combatants,[10] more than 55 submarines, 55 medium and large amphibious ships, and roughly 85 missile-equipped small combatants. The first Chinese-built carrier will likely be operational sometime in the second half of this decade. In the next decade, China will likely construct the Type 095 guided-missile attack submarine (SSGN), which may enable a submarine-based land-attack capability. In addition to likely incorporating better quieting technologies, the Type 095 will likely fulfill traditional anti-ship roles with the incorporation of torpedoes and anti-ship cruise missiles (ASCMs). Since 2008, the PLA Navy has also embarked on a robust surface combatant construction program of various classes of ships, including guided missile destroyers (DDG) and guided missile frigates in addition to more modern diesel powered attack submarines.

U.S. Air Dominance.—We see the same trend—development of systems to push U.S. freedom of movement further from the Asia mainland. China is developing an integrated air defense system that could challenge U.S. air dominance and in some regions, air superiority is challenged by 2020. The challenge to our air dominance comes primarily through the aggregation of capabilities starting with an extensive integrated air defense system (IADS), moving to development of advanced combat aircraft, to enabling technologies, primarily electronic warfare capabilities. China is demonstrating a systems approach through advanced aircraft design of 5th generation fighters, advanced combat systems, and advanced dense long range, networked air defense systems. It should be noted that others (such as Iran, Syria, and North Korea) are developing well integrated air defense systems. The PLA Air Force is continuing a modernization effort to improve its capability to conduct offensive and defensive off-shore operations such as strike, air and missile defense, strategic mobility, and early warning and reconnaissance missions. China continues its development of stealth aircraft technology, with the appearance of a second stealth fighter following on the heels of the maiden flight of the J–20 in January 2011, a 5th generation fighter scheduled to enter the operational inventory in 2018.

Vulnerability of U.S. Satellites in Space.—China has been rapidly expanding both the number, and quality of space capabilities; expanding its space-based intelligence, surveillance, reconnaissance, navigation, meteorological, and communications satellite constellations. In parallel, China is developing a multi-dimensional

[10] As of 2013.

program to rapidly improve its capabilities to limit or prevent the use of space-based assets by others during times of crisis or conflict.

China continues to develop the Long March 5 (LM–5) rocket, intended to lift heavy payloads into space, doubling the size of the Low Earth Orbit (LEO) and Geosynchronous Orbit (GEO) payloads China can place into orbit. During 2012, China launched six Beidou navigation satellites completing a regional network and the in–orbit validation phase for the global network, expected to be completed by 2020. From 2012–2013 China launched 15 new remote sensing satellites, which can perform both civil and military applications. China will likely continue to increase its on-orbit constellation with the planned launch of 100 satellites through 2015. These launches include imaging, remote sensing, navigation, communication, and scientific satellites, as well as manned spacecraft.

RESEARCH AND ENGINEERING STRATEGY

To address the challenges of an accelerating, globalized research and development environment coupled with pressurized DOD budgets and the rapid growth of capabilities in other nations, we needed to examine the strategy we are using to focus the DOD investment on high priority areas.[11] To develop the research and engineering strategy, we had to go back to first principals. Why does the Department conduct research and engineering? What does the Department expect the DOD R&E program to deliver? After examination, we contend the Department conducts research and engineering for three reasons, in priority order:

(1) *Mitigate New and Emerging Threat Capabilities*.—The Department must defend the homeland and overseas forces and national interests against threats that exist today, and threats that are still in development.

(2) *Affordably Enable New or Extended Capabilities in Existing Military Systems*.—Coincident with a tighter budget, and the fact that time is not recoverable, the DOD R&E program should focus on controlling costs, both in existing and future weapons systems.

(3) *Develop Technology Surprise*.—Finally, throughout the past century, the Nation and the Department have looked to the Department's R&E program to continually develop and mature new capabilities that surprise potential adversaries.

PRIORITY 1: MITIGATING OR ELIMINATING NEW AND EMERGING THREATS TO NATIONAL SECURITY

The Department must be prepared to meet its current and future national security missions, which include defending the homeland, securing freedom of navigation, and being able to project power. The research and engineering priorities inherent in this principal also include protecting the nation against nuclear, chemical, and biological weapons, from both State and non-State actors. This principal also includes protecting the nation against new threats, such as cyber operations and the proliferation of cruise missiles and UAVs. The final emerging vector in this area is to find solutions to the new capabilities that would prevent the US armed forces from fulfilling our global mission, such as electronic warfare and maintaining space capabilities.

Countering Weapons of Mass Destruction (C–WMD).—The Department's investment in countering weapons of mass destruction is made primarily by the Defense Threat Reduction Agency and the Chemical Biological Defense Program, as well as the Army. All totaled, the Department's investment in C–WMD is about $800 million per year. Countering weapons of mass destruction poses some unique challenges because of the urgency and immediacy of the threats, the fact that threats present low probability but high consequence events, and that there is a need for on-call, comprehensive expertise. The Defense Threat Reduction Agency emphasis for fiscal year 2015 include kinetic and non-kinetic means to counter and defeat WMD in non-permissive environments, low visibility search (and identification) for all threats (nuclear and chemical/biological), global situational awareness through mining large, diverse datasets, application of autonomy to reduce risk to the human, persistent intelligence, surveillance and reconnaissance (ISR) for WMD, WMD modelling and simulation, and operating in a high electromagnetic pulse environment.

[11] While the priorities listed below capture the cross-DOD priorities, there are still individual Service priorities they must address. These priorities do not address Naval responsibilities for the Ocean, Army responsibilities for the ground or Air Force for the Air. Rather, they comprise a set of areas that must be addressed across component. It is interesting to note the large efforts in the Services and DARPA largely align with the strategy.

To date, we have not identified the "silver bullet" solution, so a sizable portion of the C–WMD program involves international and interagency partnership.

Emerging trends over the last year includes the need to counter threats as far "upstream" or left of event as possible. Therefore, the entire C–WMD community is strengthening their program to interdict/render safe WMD before they are used.

Missile Defense.—In fiscal year 2015, the investment in missile defense S&T dropped from roughly $350 million in fiscal year 2014 to $176 million in fiscal year 2015. Yet, missile defense remains a priority. The reduction in missile defense is more than offset the Navy and by the Office of the Secretary of Defense efforts in electromagnetic rail gun technology; a nearly $200 million investment in fiscal year 2015. This push in rail gun is being made to determine if the technology is mature enough to field an inexpensive, kinetic kill system to intercept theater ballistic missiles in terminal and mid-course. The current investment supports demonstration of an advanced rail gun against a missile surrogate in 2015.

Although not a capability that will be fielded soon, the Missile Defense Agency continues to look at Directed Energy for missile defense. They are the primary investor in both hybrid (diode pumped alkaline laser) and fiber lasers. Significant demonstrations for both of these directed energy capabilities will occur in 2015 to 2016.

A strategy based on only kinetic defense which requires a high-end US missile intercept against this proliferation of missiles is cost-imposing on the United States. Our research and engineering program is also working on developing non-kinetic capabilities and less expensive kinetic capability to reduce the effectiveness of potential adversaries' missiles; we are making strides in this area.

Cyber and Information Operations.—The Department's investment in Cyber S&T in fiscal year 2015 is $510 million. With the growing reliance of modern military forces on information technology, cyber operations will play an increasingly important role in ensuring continuity of missions in the physical domains. Having effective technologies to support those cyber operations makes cyber security research an essential element in our long-term abilities to defend the Nation.

This year, the Department rebuilt the cyber S&T investment around warfighting capability requirements. We have then built a strong integrated technical foundation across the Cyber research and engineering enterprise through our Cyber Community of Interest, a group made up of Senior Executive Service representatives from the Services, NSA, and my organization. Our cyber S&T investments are guided by an S&T Capabilities Framework that captures new and emerging mission requirements including improved situation awareness and course of action analysis. The framework has been developed with participation of all the Services as well as the Intelligence Community, National Laboratories, and our federally Funded Research and Development Centers. We are placing emphasis on broadening the research beyond standard computing systems to include defending against cyber threats to tactical and embedded systems. Our cyber research includes investments in providing a testing and evaluation environment for the experimentation and testing of cyber technology across the full spectrum of capabilities to help validate and accelerate research. Additionally, and very importantly, it is a priority for the DOD to be an early adopter of emerging technologies in cyber defense and to ensure the transition of those products to our warfighters and the programs supporting them.

Though challenges remain in all areas, Cyber S&T is making progress and having significant impacts. Over the past few years, our cyber investments, from fundamental research through advanced technology demonstrations have resulted in many successes that directly benefit our warfighters and the broader defense enterprise. Some highlights are:

—Securing our telecommunications infrastructure through vulnerability assessment, tool development, and best practice dissemination;

—Developing technologies to accurately geo-locate illicit commercial wireless devices to protect our networks;

—Producing a game-changing approach to signature-free malware detection capable of defending against zero-day attacks;

—Designing a flexible, mission-based interoperability framework enabling rapid, low-cost capability integration for our cyber operation forces; and

—Developing tools and techniques that assure the secure operation of microprocessors within our weapons platforms and systems.

This year, in concert with White House Priorities,[12] we created the Cyber Transition to Practice (CTP) Initiative. The goal of this initiative is to mature and ultimately transition S&T products to operational use. The development of cyber tools frequently happens on a time scale much less than the traditional acquisition process. The CTP initiative is intended to accelerate fielding of cyber tools.

Loss of Assured Space.—Other nations have developed both kinetic and non-kinetic means to degrade or deny the U.S. space layer. Consequently, the DOD S&T program is working on developing the space capabilities our forces rely on whether or not the space layer exists. The capability may be degraded, but will also not be vulnerable. Other nations are seeking to asymmetrically disrupt our military capabilities that depend upon assured satellite communications; global systems for positioning, navigation, and timing; and on-demand ISR, even in denied areas. The U.S. will respond to these actions through increasing the resilience of our space assets so they are free from interference as well as develop alternative means to deliver the capabilities we currently obtain from our space assets.

Current technologies in development include, but are not limited to the following: improving our space situational awareness capabilities employing improved ground- and space-based systems (such as the Air Force Research Lab's 2006 demonstration of on-orbit, localized Space Situational Awareness), enhanced terrestrial and airborne communications or jam resistant communications (such as laser communications); novel timing devices decoupled from continuous access to GPS (like the Tactical Grade Atomic Clock, projected for transition to the acquisition community in 2017); high performance Inertial Measurement Units (like DARPA's High Dynamic Range Atom Sensor (HiDRA), projected for 2016, and small-form-factor anti-jam GPS antennas); and alternative ISR capabilities (which may incorporate advanced electro-optic coatings and thermal protections measures under development at the Air Force Research Lab). Finally, we have several Joint Capability Technology Demonstrations (JCTDs) to determine the viability of capabilities delivered from very small satellites. Kestrel Eye and Vector JCTDs will demonstrate the viability of small satellite tactical communications and ISR by 2016.

Electronic Warfare (Both Attack and Protection).—The Department's investment in electronic warfare (EW) S&T is about $500 million per year. This is an area that is evolving rapidly because of technology advances. The two key parameters in EW are the frequency the system operates and how complex is the signal. The concept behind electronic warfare is simple—the goal is to control your electronic signature or confuse an opponent's system if you are defending and to simplify the overall situation (reject false targets and clutter) if you are attempting to use your own electronic systems (radar, communications and radio frequency).

Electronic warfare is becoming important and more critical because the enabling technologies underlying frequency and complexity are progressing very rapidly. To address the underlying technologies, the components have coalesced around a concept called Advanced Components for EW (ACE), which is focusing on Integrated Photonic Circuits, Millimeter Wave, Electro-Optical and Infrared (EO/IR), and Reconfigurable and Adaptive RF electronics. As a whole, these technologies should improve simultaneous transmit and receive; expand instantaneous bandwidth, and allow a huge leap ahead in complexity. ACE kicked off in fiscal year 2013, with the components continuing to develop components.

In addition to the underlying technology, the Services are involved in building advanced electronic systems. We will cover two of them. The Navy's Integrated Topside program is just completing attempting to use multifunction transmitters on the top of a ship. This will reduce the number of individual systems with a unique electronic signature, and improve ship survivability.

The Home on GPS–Jam (HOG–J) is a small munition that will identify foreign GPS jammers and vector the munition into the jammer. HOG–J has had some preliminary successful tests, and could be ready to enter the inventory in 2–3 years. There are other EW systems that could be covered at the appropriate security level.

PRIORITY 2: AFFORDABLY ENABLING NEW OR EXTENDING MILITARY CAPABILITIES

The cost of Defense acquisition systems continues to be a challenge for the Department. Over the past 3 years, the Department introduced "Better Buying Power" initiatives to improve the cost effectiveness of the Defense acquisition system. Cost effectiveness and affordability of defense systems starts before the acquisition enterprise kicks in. There are two vectors to increasing affordability; technology to lower

[12] This is in direct response to the NSS Cybersecurity FY2014 Budget Priority of September 11, 2012 (section 4.a of the annex).

cost and extend life cycle, and research and engineering processes to address costs early in system development.

Systems Engineering.—The Department's systems engineering capability and capacity are critical to enabling affordability across the system life cycle of an acquisition program. The Department's systems engineers drive affordable designs, develop technical plans and specifications to support cost-effective procurement, and conduct trade-off analyses to meet program cost, schedule and performance requirements. Systems engineers are enabling strategies to identify opportunities to reduce life-cycle costs. My organization has taken a lead role in improving the Department's ability to achieve affordable programs through strong SE policy, guidance, dissemination of best practices, execution oversight and support for a healthy, qualified engineering workforce.

Through an emphasis on affordability in recently updated policy and guidance, the Department has established a clear role for systems engineers in defining, establishing, and achieving affordability goals and processes throughout the life cycle. Through required systems engineering trade space analyses, individual acquisition programs establish the cost, schedule and affordability drivers and can demonstrate the cost-effective design point for the program. These trade space analyses will be conducted across the program's life cycle to continuously assess system affordability and technical feasibility to support requirements, investments, and acquisition decisions and depict the relationships between system life-cycle cost and the system's performance requirements, design parameters, and delivery schedules. Recent emphasis on better reliability engineering has focused the Department's acquisition programs on reducing overall life-cycle costs. My systems engineering staff maintains regular and frequent engagement with acquisition programs to support the planning and execution of effective technical risk management, as well as affordability considerations. They provide regular oversight and guidance to assist the programs as they mature through the life cycle.

Developmental Test and Evaluation.—Developmental Test and Evaluation (DT&E) efforts focus on engaging major acquisition programs early in their life cycle to ensure efficient and effective test strategies, thereby ensuring a better understanding of program technical risks and opportunities before major milestone decisions. In 2013, the Deputy Assistant Secretary of Defense for Developmental Test and Engineering (DASD(DTE)) introduced the "shift left" concept—specifically to drive DT earlier in the acquisition process. Early DT&E engagement with programs not only reduces acquisition costs through efficient testing, but finding and fixing deficiencies early, well before production and operations, drastically reduces overall life-cycle costs. The DASD(DT&E) is focusing on a few key areas to improve the overall effectiveness of developmental test and evaluation; use of the Developmental Evaluation Framework, increased emphasis on testing in a mission context, earlier cyber security testing, and an increased emphasis on system reliability testing.

The Developmental Evaluation Framework is a disciplined process that results in a clear linkage between program decisions, capability evaluation, evaluation information needs, and test designs. Using the Developmental Evaluation Framework provides an efficient, yet rigorous T&E strategy to inform the program's decisions. Developmental Test and Evaluation is also moving beyond the traditional technical test focus to include testing in a mission context to characterize capabilities and limitations before production. Robust DT&E should also include early cyber security testing that previously was not tested until late in the acquisition life cycle, where deficiencies are costly to fix. Finally DT&E is focusing on increased system reliability testing. System reliability is a major driver in the affordability of future weapon systems. Improved reliability information early in the program allows acquisition leadership to understand the program technical and cost risks and take steps to improve system reliability and therefore the affordability of the system.

Prototyping.—Another way to drive down costs of weapons systems is through the expanded use of prototypes, which we use to prove a concept or system prior to going to formal acquisition. Consequently, in fiscal year 2015, we look to expand the use of developmental and operational prototyping to advance our strategic shift to a greater emphasis on future threats. In fiscal year 2015, the Department's investment in prototypes or prototype like activities is around $900 million. This includes activities that are not classical prototype efforts, but will demonstrate capabilities, such as the Navy's Future Naval Capabilities, Integrated Naval Prototypes, the Army's Joint Multi-role Helicopter and Future Fighting Vehicle, as well as Air Force Flagship programs, and the revamping of the Department's Joint Capability Technology Demonstrations and Emerging Capabilities Technology Development programs.

The RAND Corporation provides a good definition for prototyping, describing it as "a set of design and development activities to reduce technical uncertainty and to

generate information to improve the quality of subsequent decisionmaking."[13] We distinguish between two types of prototyping activities. Developmental prototyping demonstrates feasibility of promising emerging technologies and helps those technologies overcome technical risk barriers. Operational prototyping focuses on assessing military utility and integration of more mature technologies.

A recent example of an operational prototype is Instant Eye, a one pound quadcopter. We outfitted Instant Eye with an electro-optical camera and IR illuminator, bringing a field repairable, overhead surveillance capability to the soldier in the field at a unit cost of less than $1,000. Instant Eye would go on to provide targeting information for the neutralization of seven insurgents waiting to ambush a U.S. combat patrol.

Joint Multi-Effects Warhead System (JMEWS) is a good example of a higher-risk, higher reward developmental prototype. The JMEWS project took on the challenge of in-flight targeting and re-tasking of the Tomahawk Land Attack Missile (TLAM). JMEWS' flexible lethality increases the combat power of these expensive weapons by tailoring the TLAM flight profile for best effect, taking advantage of information often not available until after the weapon has launched. With the developmental prototyping effort demonstrating the essential technical aspects, all that remains for Navy is to integrate JMEWS into the TLAM program of record.

Throughout the history of the Department, periods of fiscal constraint have been marked by the use of prototypes to mature technology and keep design teams active in advancing the state of practice. We will use prototyping to demonstrate capability early in the acquisition process. Prototyping will also be used to improve capability development methods and manufacturing techniques, evaluate new concepts, and rapidly field initial quantities of new systems. Prototyping's ability to evaluate and reduce technical risk, and clarify the resource picture that drives costs makes it a critical piece of the larger research and engineering strategy. Put simply, by prototyping in research and engineering, we can focus on key knowledge points and burn down the risk before the risk reduction becomes expensive.

Energy and Power.—Energy and Power Technology has a strong focus of reducing DOD operational energy risks and costs. Power requirements of new DOD systems continue to grow every year, and energy is a major cost driver and logistic burden. The Department spends approximately $300 million per year on Energy and Power science and technology. Some significant programs are:

Unmanned Underwater Vehicles—Air Independent Propulsion (UUV–AIP).—The Navy program is developing and delivering long endurance, scalable air-independent propulsion solutions for UUVs. Highly efficient fuel cell technologies will provide extended mission duration in excess of 60 days, well beyond the current and projected capability of batteries. Fuel cells are also being assessed by other Services to extend duration of UAVs and UGVs. These systems are already spinning out to industry.

The Integrated Vehicle Energy Technology (INVENT).—The Air Force INVENT program is developing power and thermal management technologies and architectures that not only address today's aircraft performance limits but also work with adaptive cycle engines to enable next generation game changing high power airborne capabilities. There are related Service initiatives to realize higher performance, more fuel efficient designs for rotorcraft and ground vehicles.

Advanced Vehicle Power Technology Alliance (AVPTA).—The Army is working collaboratively with DoE (with secondary partners from the National Labs, industry and academia) to accelerate energy-related R&D initiatives into new vehicle designs. Current efforts include: (1) advanced combustion, engines and transmission with the help of Sandia National Laboratory; (2) examination of lightweight structures for vehicles (partnering with General Dynamics); (3) energy recovery and thermal management for improved efficiency and reduced emissions (industry partner, Gentherm); (4) advanced fuels and lubricants; (5) integrated starter-generators (ISGs) without rare earth permanent magnet materials (partners, Remy Intl and Oak Ridge National Laboratory); and (6) computer-aided engineering for electric drive batteries (CAEBAT).

Engineered Resilient Systems.—To address the need for more affordable and mission-resilient warfighting systems, we are developing an integrated suite of modern computational modeling and simulation (M&S) capabilities and engineering tools aligned with acquisition and operational business processes to transform engineering environments under the Engineered Resilient Systems (ERS) initiative. The ERS tool suite allows warfighters, engineers, and acquisition decisionmakers to rapidly assess the cost and performance of potential system designs by providing many

[13] "From Marginal Adjustments to Meaningful Change", pg 64, Jeffrey Drezner and Meilinda Huang, RAND Corporation, 2010.

data-driven alternatives resulting in systems which are less sensitive to changes in external threats, mission needs, and program constraints. ERS has already demonstrated that the insertion of advanced S&T models, tools and techniques into early phases of engineering processes and decisionmaking will positively impact effectiveness, affordability and sustainability of defense systems, thus addressing these most critical challenges head on. These new M&S-based frameworks adopt the most advanced design and modeling approaches of government, industry and academia to enable our Nation to meet emergent threat, while insuring that we can do that affordably, today and in an uncertain future.

PRIORITY 3: CREATING TECHNOLOGY SURPRISE THROUGH SCIENCE AND ENGINEERING

The third and final reason the Department conducts research and engineering is to create surprise to potential adversaries. Previous Department of Defense investment in basic and applied research has a long history of developing technologies that led to superior capabilities. The DOD research program led to stealth, the Internet, synthetic aperture radar, precision weapons, infra-red focal planes and night vision devices, among others. Frequently, when investing in basic research, we don't know the specific application that will emerge; in fact, by definition, basic research is conducted without a specific product or system in mind.

The Department invests in a structured way to create surprise. Creation of surprise requires a robust basic research program coupled with a strong applied research. While it is not really possible to know where technology surprise will come from, there are several areas that highlight the possibility; we will discuss several of them in increasing level of maturity. The least mature is quantum science, followed by nanotechnology, autonomous systems, human systems, and then finally, directed energy systems.

Quantum Sciences.—The discoveries a century ago of the quantum properties of the atom and the photon defined and propelled most of the new technology of the 20th century—semiconductors, computers, materials, communication, lasers—the technological basis of much of our civilization. Now, the next quantum revolution may define new technological directions for the 21st century, building upon the intersection of quantum science and information theory. Consequently, the DOD is increasing its basic research investment in Quantum Information Science (QIS). QIS exploits our expanded quantum capabilities in the laboratory to engineer new properties and states of matter and light literally at the atomic scale. We are already developing new capabilities in secure communication, ultra-sensitive and high signal to noise physical sensing of the environment, and a path to exponentially faster computing algorithms in special purpose computers. The DOD research funding has driven quantum sciences in the past decade. This funding has led to the demonstration to measure time through cold atom research at 1,000 times more accurate than GPS. Using quantum sciences, the DOD is likely within 10 years of fielding an affordable timekeeping system that will cut our tether to GPS. We are building in the laboratory gravity sensors of unprecedented sensitivity, opening the possibility of remote detection of tunnels (or submarines). Other military applications are just being realized, but quantum science is a technology that will provide surprise.

Nanoengineering/Nanotechnology.—QIS is based on the ability to control atoms. Nanoengineering also deals with the ability to develop and engineer systems at the molecular level. This will, in turn, lead to new system level capabilities. For instance, one of the limitations to systems like directed energy is thermal management. By designing systems at the molecular level, it is possible to increase thermal management by several orders of magnitude. Materials like "metamaterials" (engineered materials for specific properties) provide a promise of development of radars and electromagnetic systems that operate much more effectively at much broader frequency ranges. Metamaterials are especially intriguing because through clever design and dissimilar materials integration, properties that are never seen in nature's materials may be obtained. An example from the Navy's fundamental research realm is the investigation of a metamaterial suitable for antennas. This material system could become transparent to radio frequency waves when exposed to high power radio frequency radiation or pulses, preventing the coupling of this energy to an aircraft's electronic systems and, thereby, avoiding damage. Engineered nanomaterials and nanotechnology research remain very competitive in our research portfolio for their potential to provide capability advantage. Both the Navy and Army have explored coatings based on materials with nanometer dimensions that have wear and corrosion resistance superior to traditional and often hazardous metals. Most recently a nanocrystalline coating based on nickel-tungsten alloys has demonstrated properties exceeding hard chromium coatings without the potential environmental problems of chromium. One of the most exciting applications for engi-

neered nanomaterials for defense and the whole economy is catalysts. The Air Force is supporting research on nanoparticle catalysts that are much more efficient in eliminating methane, a greenhouse gas, from exhausts while using the same quantity of the precious metal palladium and the rare earth element cerium. Energetic nanomaterials comprise one area of nanotechnology that is of interest primarily to defense at this time. The Army is examining highly reactive, energetic materials based on metals and metal oxides that are much less sensitive that traditional explosives. Because the DOD is committed to prudent development and application of new materials, we are studying the materials for any potentially unusual toxic properties based on their chemistry or extremely small particle size.

Autonomy.—A major cost driver to the Department of Defense is the force structure but, technology is maturing to augment the human, possibly keeping the warfighter out of harm's way and reducing the numbers of warfighters needed to conduct operations. Autonomous capabilities range from software to aid the intelligence analyst in processing exploitation dissemination (PED) through very complex networked autonomous air systems working in tandem with unmanned ground or undersea vehicles. We could field simple autonomous systems within a couple of years, but true autonomy will take years to realize. Autonomous systems are truly multidisciplinary, in that they rely on technologies ranging from sensors that understand the environment, to software algorithms that aid decisionmaking or decide to seek human assistance. Through autonomy, we seek to reduce the manpower required to conduct missions, while extending and complementing human capabilities. The Department has four technical areas of focus for investments in Autonomy: Human and Agent System Interaction and Collaboration; Scalable Teaming of Autonomous Systems; Machine perception, Reasoning and Intelligence; and Test, Evaluation, Validation, and Verification. Built around these four technical areas, we launched an experiment last year to develop an in-house capacity in autonomous systems. This experiment, called the Autonomy Research Pilot Initiative (ARPI), funded seven proposals to work on technologies in one of the four technical areas above. The awards were for 3 years, and had to be completed in DOD laboratories by DOD personnel. ARPI efforts include: Autonomous Squad Member—enabling robots to participate in squad-level missions alongside soldiers; and Realizing Autonomy via Intelligent Adaptive Hybrid Control-increasing robustness and transparency of autonomous control to improve teaming of unmanned vehicles with each other and with their human operators. Advancement of technologies from the successful Department investment in the four technical areas will result in autonomous systems that provide more capability to warfighters, reduce the cognitive load on operators/supervisors, and lower overall operational cost.

Human Systems.—Previous wars were won by massing power through weapons systems. It is not clear that will be the case in future conflicts. With the proliferation of sensors and data, future conflicts may well be won by the person that can react quickest. Studies of human cognition suggest that cognitive response times can be reduced by using display systems that present information using multiple sensory modalities. Such a reduction would give the force that is enabled with these technologies the ability to process more information, faster than their adversaries. Additionally, we are learning how to tailor training to adapt to individual students' unique needs, leading to reductions in the time needed to acquire expertise. Reducing the time to train forces to an advanced level of competence offers another way to respond faster than our adversaries. Additionally, robots, unmanned vehicles and other advanced technologies continue to be deeply integrated with our warfighters. We are developing new methodologies and technologies to enable our warfighters to interact with these systems as naturally as they do with their human counterparts leading to faster and more accurate responses by these "hybrid teams". Lastly, we are optimizing warfighter physical and cognitive performance for long durations, in dynamic and unpredictable environments, through personalized conditioning and nutritional regimens.

Directed Energy.—One of the most mature "game changing" technology areas is Directed Energy, and specifically, High Energy Lasers. High Energy Lasers have been promised for many years, but these lasers were always based on chemical lasers, which are difficult to support logistically, and the byproducts are toxic. Over the past several years, however, solid state (electric) lasers have matured, largely through the Joint High Power Solid State Laser, a cross DOD effort to develop a 100 kilowatt (KW) laser. At close range, 10–30 KW is lethal. The JHPSSL was demonstrated in 2009. Since then, the Services have worked on packaging a solid state laser that could be deployed. In summer 2014, a 30 KW laser will be prototyped on the USS *Ponce* in the CENTCOM area of responsibility. In December 2013, the Army demonstrated the High Energy Laser Mobile Demonstrator at White Sands missile range. This 10 KW laser successfully engaged nearly 90 percent of the avail-

able targets. This system will be further demonstrated in a maritime environment at Eglin Air Force Base.

RELIANCE 21

The Department's Research and Engineering (R&E) Enterprise is wide-ranging, and is the foundation of the Department's technological strength. The enterprise includes DOD laboratories and product centers, other government laboratories, federally funded research and development centers (FFRDC's) and University affiliated research centers (UARCs), U.S. and allied universities, our allied and partner government laboratories, as well as industry. Last year I took the opportunity to brief the members of this Committee as my impetus to develop a strategy for the R&E Enterprise; this strategy was discussed earlier. What is important this year is putting in place the structure to attempt to optimize the S&T investment. Consequently, the Department's S&T Executives and I have worked to put in place Reliance 21. Under Reliance 21, most of the Department's S&T program will be managed in one of 17 cross-cutting portfolios. Each of these portfolios will be made up of Senior Executive or Senior Leader from each Service and Agency with investment in the area. These teams are building integrated roadmaps, and beginning the process of integrating allied and industry efforts onto our roadmaps. Each year, about one third of the portfolios will be reviewed, in depth to the S&T Executives, who will approve or redirect the roadmaps. The roadmap will include the technical and operational objective, the critical technical efforts needed to meet the objective, the gaps to reaching the objectives, and an assessment of where the portfolio leads recommend changes. The 17 portfolios are all called Communities of Interest (COI). Done correctly, management of a large portion of the Department's S&T execution will be collaboratively achieved by the COIs.

WHAT CONGRESS CAN DO FOR THE DEFENSE S&T PROGRAM

We are the most technologically advanced military in the world but, as Secretary Hagel so aptly stated in his remarks on the 24th of February of this year, "we must maintain our technological edge over potential adversaries".[14] I have outlined what we are doing with the resources that we have been given and what we plan to do with the resources in the fiscal year 2015 President's budget. Success, however, will depend on your support. In that regard I have two requests.

I ask that you enact the Research, Development, Test and Evaluation portion of the President's Budget as submitted. We spent a lot of time to balance the program to best meet DOD priorities.

The President's budget seeks funding for fiscal year 2016–2021 that is above the estimated sequestration levels under current law. As pointed out earlier, with no relief from the BCA in the out years, we expect modernization and readiness accounts to bear the brunt. This would heighten the increased risk we are already seeing. Simply, at that sequestration level, we expect continued erosion of the S&T and RDT&E accounts.

Second, I would ask that you support our efforts in prototyping. We are expanding the use of developmental and operational prototyping in lieu of formal acquisition programs. Throughout the history of the Department, during periods of fiscal constraint, the Department has used prototypes to mature technology and keep design teams intact and moving forward. Prototyping has another advantage—it allows the Department to build a capability early in the acquisition process, before all the structure affiliated with the acquisition process begins. By prototyping in research and engineering, we can acquire valuable knowledge and buy down risk and lead time to production at relatively low cost.

CLOSING

In summary, the last year has been a challenge to the Department's S&T program. The risk to our force is growing, and the need for the S&T community is likewise increasing. We have shifted our focus to protecting the future by countering anti-access, area-denial threats, addressing the increasing complexity of adversary's weapons systems, shortening the maturation time of developing our own systems, and addressing the erosion of the United States' stature in international science markers. We need your help to remove the crippling uncertainty associated with sequestration so that we can transition to the balance of force structure, readiness and modernization the country needs and deserves from us.

Senator DURBIN. Thank you.

[14] Hagel, 24 February 2014.

Dr. Prabhakar.

STATEMENT OF DR. ARATI PRABHAKAR, DIRECTOR, DEFENSE ADVANCED RESEARCH PROJECTS AGENCY

Dr. PRABHAKAR. Thank you, Mr. Chairman, Senator Cochran, and members of the subcommittee. It is very good to be here today with my colleagues, and I appreciate the chance to talk with you all.

DARPA is part of this Defense Department's science and technology community. We are also part of the larger national ecosystem for research and development. Within these communities, we have a particular role and that role is to make the pivotal early investments that change what is possible so that we can take big strides forward in our national security capabilities.

And very much in keeping with your comments, Mr. Chairman, DARPA too was started in the wake of Sputnik. So we have been around pursuing that mission for 56 years. We were created precisely to prevent that kind of technological surprise that Sputnik had created for us. We have delivered on our mission for 56 years by creating a few surprises of our own, and while our output is technology, we really count our successes when those technologies change outcomes. So every time a stealth aircraft evades an air defense system, every time a soldier on the ground can place himself precisely using GPS so that he can call for fires, every time that a radar tells a carrier strike group about a threat that is out there long before it sees us, that is when we have succeeded in our mission at DARPA because in each of those cases, we made those early investments. We showed what was possible.

And in every one of those cases, it took a much larger community to turn those ideas into real capabilities. Of course, it took our partners that we work with very closely across the services in science and technology. It also took the services' further development work and acquisition efforts. Every one of these technologies traces back to research often conducted in universities or other labs. Every one of these advances relied on industry, defense, and commercial industry, large companies and small. And at the end of the day, it took warfighters to turn those technologies into real military capabilities.

So that is how that whole ecosystem works for that DARPA portion of it. That mission that we have had of breakthrough technologies for national security has not changed over 56 years. The world in which we work continues to change, but that core mission is still why our people charge through the front doors every single morning.

And so let me just share with you a few of the things that we are doing today to deliver on our mission in the context of the world that we are living in.

One thing that we see happening today is that the classic approach to major military systems has gotten so costly and inflexible that it is really not going to be effective for the challenges that we are going to face in the future. So a number of our investments at DARPA are rethinking complex military systems, and we are coming up with powerful, new approaches for new radars and weapons,

new ways to do navigation and communications, new ways to architect space systems.

In a very different arena, we can see the massive scale of information changing every aspect of national security. So here we are creating first a new breed of cybersecurity technologies so that we can actually trust the information that we have become so reliant on.

We are also inventing new tools to keep up with and to start using this explosion of data. One example is a new program that we have that is tackling the networks involved in human trafficking. Today these trafficking networks very easily can hide in the vast data that is online. So really finding ways to see those bad actors in vast volumes of data is part of the objective of our programs.

And then in a very wide range of research areas today, we see the seeds of what could be the next generation of technological surprise. One area that I think is quite vibrant right now is in the research where biology is intersecting with engineering. And here we are investing to create the capability to outpace the spread of infectious disease, to understand and even harness brain function, and to speed the development of new chemistries and materials coming out of synthetic biology.

So, obviously, I would be happy to talk about any of these or other efforts in the DARPA portfolio.

But let me just end my remarks this morning by saying that when I talk with our leaders in the Pentagon and here on Capitol Hill, I often feel that I can see the weight of our national security challenges weighing on them and on you. I think we all feel it. We do live in a volatile world. We all see the shifting threats. We are all dealing with constrained budgets and the corrosive effects of sequestration. But I also know that American innovation has turned the tide time and again, and I am really confident that the work that we are all doing today can do that again for the years to come.

PREPARED STATEMENT

Your support to make that possible to this point has been essential. So I really thank you for that. I would also like to ask for your full support of the President's budget request for fiscal year 2015 so that we can continue these vital investments.

Thank you, and I look forward to answering your questions along with my colleagues.

[The statement follows:]

PREPARED STATEMENT OF DR. ARATI PRABHAKAR

Chairman Durbin, Vice Chairman Cochran and Members of the Subcommittee, thank you for the opportunity to testify before you today. I am Arati Prabhakar, Director of the Defense Advanced Research Projects Agency, DARPA. It is a pleasure to be here with my colleagues across the Department of Defense (DOD) Science and Technology (S&T) community. Our organizations work together every day to advance our Nation's defense technologies. DARPA plays a particular role in this community, and in the broader U.S. technology ecosystem. That role is to anticipate, create, and demonstrate breakthrough technologies that are outside and beyond conventional approaches—technologies that hold the potential for extraordinary advances in national security capability. This mission and our current work and plans are the focus of my testimony today.

DARPA'S MISSION AND THE DIVERSE THREATS FACING OUR NATION

In the fall of 1957, a polished metal sphere, 23 inches in diameter and launched from Soviet soil, began its orbit around the Earth, passing over American skies approximately every 96 minutes and initiating the space age, a space race, and a new era in the long struggle to maintain American military and technological superiority. Starting DARPA was one of the pivotal choices our Nation made in the wake of Sputnik. America today enjoys a hard-earned, privileged position, with tremendous military might, economic strength, and social and political freedom. Yet, as this Subcommittee knows well, risk is ever evolving in our complex and dynamic world. Regional instability, shifting military and economic positions, demographic and natural resource trends—these forces drive constant change in our national security environment. Today and in the years ahead, our potential adversaries will still include nation states, but also smaller, less well defined bad actors and an increasingly networked terror threat. National security challenges will continue to range from the acute to the chronic. This is the threat environment that shapes our technology investments today at DARPA.

Adding to the security challenges we face is the fact that technology and its accessibility have changed so significantly. Startlingly powerful technologies—semiconductors, information systems, and nuclear and biological technologies among them—are now globally available to a much wider swath of society, for good and for evil. And while the cost of some technologies has dropped precipitously, other technology and non-technology related costs have risen steeply, leading DOD to make difficult choices about our operational capabilities. That means our assumptions about the cost of military systems must change. These factors will also continue to shape our investments at DARPA.

DARPA was designed and built for just this kind of shifting, challenging threat environment. Through more than 5 decades of tumultuous geopolitical and technological change, we have delivered outsized impact by focusing on our mission of breakthrough technologies for national security. We imagine groundbreaking new technology advances with the potential for defense applications. We bring the best of those ideas to fruition by providing the right mix of research support, intellectual freedom, and responsible oversight to outstanding performers in industry, academia, and other government organizations. And we facilitate the transition and operationalization of these new, paradigm-shifting capabilities.

HARNESSING COMPLEXITY TO CREATE EXCEPTIONAL NEW CAPABILITIES: DARPA'S PROGRAMS

Like most truly great problems that confront us, today's diverse threats can either be viewed as an imposing barrier or as an opportunity to overcome a difficult challenge. Either way, I believe our national security will depend upon how we deal with complexity. DARPA chooses to tackle complexity by harnessing it, and our programs reflect that approach of playing offense. We do that with game-changing new capabilities and with layered, adaptable, multi-technology systems. We do that by catalyzing major new national technology advances and by rapidly exploiting commercially available technologies. And at a time when systems cost is the difference between building operational capability or just building PowerPoint, we do that by striving to invert the cost equation for our military.

DARPA has made important strides forward in delivering key breakthrough technologies. In discussing how we are tackling various aspects of technological complexity, I will update you on several new programs that we have launched, results we have achieved, and transitions that have been accomplished or are in process.

Rethinking Complex Military Systems

Much of DARPA's work rethinks complex military systems, recasting today's approach with the intention of achieving far greater capabilities at lower cost. Today, our military relies upon the meshing of electronic, optical, software, and mechanical components to create satellites and the vehicles, aircraft, and ships that carry our Warfighters into battle. We also depend upon this integration of components in designing and producing the weapons these men and women must be prepared to use. That is not new. But today, these technology components are becoming ever more complex. Consider: radar systems have thousands of antenna elements, platforms run millions of lines of code, and integrated circuits are made of billions of transistors. These many components are also now interdependent and interacting to an unprecedented degree. And, of course, these platforms and mission systems must operate in an environment that will be increasingly contested by others with access to ever-improving global technologies. All these factors contribute to the high cost, long development times, and inflexibility of today's most advanced systems. This de-

mands that we rethink—sometimes in fundamental ways—how we approach the next generation of defense systems.

Let me give you a few examples of how DARPA is tackling this challenge from our portfolio of programs.

Robust Space

In times of conflict, our Nation's leaders count on our military to wage precise, overpowering war. This type of highly effective warfighting is critically dependent on space—for imaging and sensing, for communications, for navigation, even for keeping time. As never before, we require ready access to space and strategic control over our assets in space. But while space is becoming increasingly important, it's also becoming increasingly crowded and contested, and DOD's ability to access and operate in space has become less nimble and more expensive over many years. DARPA has several programs underway to change that equation.

Rapid Launch: Experimental Space Plane (XS-1) and Airborne Launch Assisted Space Access (ALASA)

Imagine a world in which getting a satellite into orbit can be as quick and reliable as an aircraft takeoff. Our new Experimental Spaceplane is designed to take a 3,000- to 5,000-pound payload into orbit using an expendable upper stage, all for under $5 million; that is one-tenth the cost of a comparable launch today. Our ALASA program focuses on 100-pound payloads for less than $1 million. Even more striking is our goal of providing satellite launches for these payloads with just 24 hours' notice.

Avoiding Collisions in Space: Space Surveillance Telescope (SST)

In space, one major challenge is simply a lack of knowledge of what is around you. With satellite traffic and the risk of space collisions growing, space domain awareness is a top priority. DARPA's SST enables much faster discovery and tracking of previously unseen, hard-to-find objects in geosynchronous orbits. We expect it to be ready for operations within 2 years in Australia as a result of a memorandum of understanding signed last November by Secretary of Defense Hagel with his counterpart. Once operational on the Northwest Cape of Australia, SST will provide detection and tracking of satellites and space debris at and near geosynchronous orbits within the Asia-Pacific region, information U.S. space operators can use to better protect critical U.S. and Allied space-based capabilities.

Lowering the Risk and Cost for Satellites

Communications satellites in geosynchronous orbit, approximately 36,000 kilometers above the Earth, provide vital communication capabilities to Warfighters and others. Today, when a satellite fails, we usually face the expensive prospect of having to launch a brand new replacement. Our Phoenix program strives to develop and demonstrate technology to robotically service, maintain, and construct satellites in the harsh environment of geosynchronous orbit. Phoenix is also exploring a paradigm change to satellite design that would enable ground and on-orbit assemble-able platforms to potentially lower the cost of next-generation space systems by a factor of 10 compared to what is possible today.

Winning in Contested Environments

Space is not the only environment that is growing more crowded and dangerous. We must always anticipate an actively contested environment as we look ahead to potential challenges from future adversaries. Today, we are dependent on centralized command and control, and the fragile lines of communications linking tactical assets to decision makers. While DARPA has multiple programs addressing these challenges for the air, ground and sea, a common thread is the development of technologies to shift and distribute capability at the forward edge of the battle and to adapt quickly to a changing technology landscape.

Long-Range Anti-Ship Missile (LRASM)

Today's anti-ship missiles face challenges penetrating sophisticated air defense systems from long range. As a result, Warfighters may require multiple missile launches and overhead targeting assets to engage specific enemy warships from beyond the reach of counter-fire systems. In important progress to overcome these challenges, the DARPA-Navy LRASM program has had a series of successful flight tests on a precision-guided anti-ship standoff missile. That will reduce dependence on intelligence, surveillance and reconnaissance platforms, network links, and Global Positioning System (GPS) navigation in electronic warfare environments. DARPA is collaborating with the Navy via a new joint program office, helping to move this leap-ahead capability to deployment very quickly.

Distributed Battle Management (DBM) and Communications in Contested Environments (C2E)

Under our Air Dominance Initiative, DARPA, the Air Force and the Navy together have been exploring systems-of-systems concepts in which networks of manned and unmanned platforms, weapons, sensors and electronic warfare systems interact to succeed in a contested battlespace. These approaches could offer flexible and powerful options to the Warfighter, but the complexity introduced by the increase in the number of employment alternatives—particularly in a dynamic situation—creates a battle management challenge. Further complicating matters, in future conflicts U.S. forces may face degradation or denial of critical communications capabilities essential for coordination and shared situational understanding.

We recently launched two programs that address these challenges. The Distributed Battle Management (DBM) program seeks to develop control algorithms and demonstrate robust decision-aid software for air battle management at the tactical edge. Our new Communications in Contested Environments (C2E) program is, at the same time, exploring the use of reference architectures to enable robust, scalable and rapidly evolvable airborne communications networks.

Dominating the Electromagnetic Spectrum

The challenge of the threat environment extends to the airwaves as well, a reality that also is beginning to affect commercial and civil activity as demand continues to grow for access to the electromagnetic spectrum. The United States and our Allies learned an important lesson in World War II, when we became the first to control and take advantage of one small part of the spectrum—the range occupied by radar. By many assessments, Allied dominance in radar technology was pivotal to our winning that crucial war. Today we can say that the next war may be won by the nation that controls the electromagnetic spectrum over the full range of wavelengths—a degree of control that can ensure dominance in communications and in the important linked domains of timing, location and navigation. It also can ensure dominance in seeing what our adversaries are doing, and in controlling what they see of us—both our capacity to hide things from their sensors and our capacity to make "visible" an array of things that are not really there.

Spectrum Challenge

One approach to dominating the spectrum is simply to be more nimble, both in sensing and using whatever portions of the spectrum are available. Radios, for example, lack agility, despite the fact that they are used for the most mundane to the most critical of communications, from garage door openers to first responders to military operations. Wireless devices often inadvertently interfere with and disrupt radio communications, and, in battlefield environments, adversaries may intentionally jam friendly communications. To stimulate the development of radio techniques that can overcome these impediments, DARPA launched its Spectrum Challenge, a national competition to develop advanced radio technology capable of communicating in congested and contested electromagnetic environments without direct coordination or spectrum preplanning. We expect to see a massive increase in innovation when the teams return for the final part of the Challenge with promising results for future applications.

Moving to New Frequency Domains: Terahertz Electronics (THz)

Another way to control the spectrum is to move to new frequency domains, where hardware limitations currently prevent us from operating effectively. The submillimeter wave, or terahertz, part of the electromagnetic spectrum falls between the frequencies of 0.3 and 3 terahertz, between microwaves and infrared light. Unlocking this band's potential may benefit military applications such as high-data-rate communications, improved radar, and new methods of sensing. But access to these applications has been limited due to physics and our limited understanding.

Researchers under DARPA's Terahertz Electronics (THz) program have designed and demonstrated a 0.85 terahertz power amplifier using a micromachined vacuum tube; we believe it to be a world first. The vacuum tube power amplifier is one achievement of the broader THz program, which seeks to develop a variety of breakthrough component and integration technologies necessary to 1 day build complex terahertz circuits for communications and sensing.

Many more DARPA programs also rethink complex military systems. These include efforts to use the undersea environment to observe and access regions around the world; to rapidly bring advances in commercial technology to the battlefield; to develop hypersonic technologies for advanced speed, reach and range; and to create new distributed architectures for the contested environments of the future.

Information at Scale

Let's consider a different aspect of complexity. As the information revolution continues, the sheer scale and variety of data seems immensely, and perhaps overwhelmingly, complex—but this challenge also presents major opportunities.

Insight to Enhance Analysts' Capabilities and Performance

Military intelligence analysts face the monumental and escalating task of analyzing massive volumes of complex data from multiple, diverse sources such as physical sensors, human contacts, and contextual databases. DARPA's Insight program addresses the need for new tools and automation to enhance analyst capabilities and performance. The program seeks to enable analysts to make sense of the huge volumes of intelligence-rich information available to them from existing sensors and data sources. Automated behavioral learning and prediction algorithms help analysts discover and identify potential threats, as well as make and confirm hypotheses about those threats' potential behavior. The goal is a comprehensive operating picture in which expedient delivery of fused actionable intelligence improves support of time-sensitive operations on the battlefield. We are working closely with the Army and the Air Force to transition operational capabilities to programs of record.

MEMEX: A Different Approach to Search

Despite the vast amounts of data available, today's Web searches use a centralized, one-size-fits-all approach that searches the Internet with the same set of tools for all queries. While that model has been wildly successful commercially, it does not work well for many government use cases. Current search practices miss information in the deep Web—the parts of the Web not indexed by standard commercial search engines—and ignore shared content across pages.

To help overcome these challenges, DARPA launched the Memory and Exploration of the Internet for Defense (MEMEX) program. This ambitious effort seeks to develop domain-specific search technologies and revolutionize the discovery, organization and presentation of the types of search results needed for national security concerns. MEMEX's initial focus will be human trafficking, which is a factor in many types of military, law enforcement and intelligence investigations and has a significant Web presence to attract customers.

Mining and Understanding Software Enclaves (MUSE)

Information at scale includes not just data, but software code as well. Within the last few years, there has been a tremendous explosion in the number of open source projects and the size of codebases these projects contain. Software repositories today are estimated to contain more than 100 billion lines of code, and the number continues to grow. Open source software is widely used in mission-critical DOD systems as well as in the commercial world. DARPA's new Mining and Understanding Software Enclaves (MUSE) program aims to harness the scale and complexity of this array of software to instigate a fundamental shift in the way we conceive, design, implement, and maintain software. If successful, MUSE could lead to a new programming methodology, leading to automated mechanisms for improving resilience, reducing vulnerabilities, and simplifying the construction of software systems.

High-Assurance Cyber Military Systems (HACMS)

Embedded systems form a pervasive network that underlies much of modern technological society. Such systems range from large supervisory control and data acquisition (SCADA) systems that manage physical infrastructure to medical devices such as pacemakers and insulin pumps, to computer peripherals such as printers and routers, to communication devices such as cell phones and radios, to vehicles such as automobiles and airplanes. These devices have been networked for a variety of reasons, including the ability to conveniently access diagnostic information, perform software updates, provide innovative features, lower costs, and improve ease of use. But researchers and hackers have shown that these kinds of networked embedded systems are vulnerable to remote attack, and such attacks can cause physical damage while hiding the effects from monitors. DARPA launched the High-Assurance Cyber Military Systems (HACMS) program to create technology to construct high-assurance cyberphysical systems. Achieving this goal requires a fundamentally different approach from what the software community has taken to date. If successful, HACMS will produce a set of publicly available tools integrated into a high-assurance software workbench, which will be widely distributed for use in both the commercial and defense software sectors. For the defense sector, HACMS will enable high-assurance military systems ranging from unmanned vehicles to weapons systems, satellites and command and control devices. In an early demonstration of the

program, we are running first-of-its-kind provably correct software on a commercially available automobile.

These programs are examples from DARPA's broader portfolio in cyber and information at scale. Other efforts are developing new technologies to enable distributed computer systems to work through attacks; permit trustworthy Internet communications in untrusted environments; automate the discovery, identification and characterization of new malware; provide DOD with military cyber capabilities; and automatically process text information to discover meanings and connections that might otherwise not be readily apparent to analysts.

Biology as Technology

A third area of complexity of growing interest and importance to DARPA—and among the most promising for future major capabilities—is the idea of biology as technology. Biology is nature's ultimate innovator, and any agency that hangs its hat on innovation would be foolish not to look to this master of networked complexity for inspiration and solutions.

Living Foundries

Synthetic biology—a hybrid discipline of biology and engineering—has already proven itself capable of using customized bacteria to produce medicines, and now it is heading toward even more interesting applications as we harness it to create entirely new chemistries. Our Living Foundries program seeks to develop the next-generation tools and technologies for engineering biological systems, compressing the biological design-build-test cycle in both time and cost. For example, the program has demonstrated the ability to generate a suite of novel bioproducts in weeks rather than years. The program is also producing new classes of materials with novel properties that can enable a new generation of mechanical, optical and electrical products.

Rapid Threat Assessment (RTA)

Even as we develop new materials and tools for engineering biological systems, we understand that we must also be prepared to react quickly to how our adversaries may seek to use similar capabilities. This concern is not new: novel chemical and biological weapons have historically been mass-produced within a year of discovery. Using current methods and technologies, researchers would require decades of study to gain a cellular-level understanding of how new threat agents affect humans. This gap between threat emergence, mechanistic understanding and potential treatment leaves U.S. forces and populations here and around the world vulnerable.

DARPA launched the Rapid Threat Assessment (RTA) program with an aggressive goal: develop methods and technologies that can, within 30 days of exposure to a human cell, map the complete molecular mechanism through which a threat agent alters cellular processes. This would give researchers the framework with which to develop medical countermeasures and mitigate threats. If successful, RTA could shift the cost-benefit trade space of using chemical or biological weapons against U.S. forces and could also apply to drug development to combat emerging diseases.

Brain Function Research

In an era when harnessing complexity will be the sine qua non of success, it should not be surprising that DARPA has a particular interest in tackling the brain. DARPA's interest starts with our desire to protect and assist our Warfighters, whether it means preventing or treating traumatic brain injury, easing the effects of post-traumatic stress disorder, or learning to operate sophisticated prosthetic limbs with thoughts alone, as is now increasingly possible with our new and exciting technologies. These advances also open the door to a much deeper understanding of how humans interact with the world around them—new insights that may fuel the next revolution in how we work with complex technologies and systems. Over the past year, we launched several new brain function-related programs that are now getting underway. These efforts are part of the President's initiative in brain research. Recently, we have made unprecedented advances in developing advanced prosthetic arm systems and methods to restore near-natural movement and control, as demonstrated by the DEKA Arm System approved by the Food and Drug Administration last week.

DARPA's biology-related investments also include diagnostics and novel prophylaxes to outpace the spread of infectious disease and new methods to accelerate the testing of critical therapeutics.

New Frontiers

Consistent with our mission to prevent technological surprise by creating it, DARPA continues to invest across a wide range of fields where we see promising research that could lead to powerful technology capability. These investments are the seeds of what my successors, perhaps 5, 10, or 15 years from now, will be describing to you as technology revolutions.

I described earlier our work in developing new algorithms, software and architectures that allow us to better mesh our electronic, optical and mechanical components together. What about those components themselves? We are pushing the frontiers of physics to make them dramatically smaller, or more capable, or both.

iPhod, COUGAR, and ORCHID

Consider the many ways we are developing to harness light, which will directly affect the size, weight, cost and performance of military components ranging from small navigation sensors to phased array radars and communication antennas. One recently concluded program (iPhod) successfully miniaturized tools for creating delays in light transmission, while another (COUGAR) demonstrated unique designs in hollow-core fibers, which guide light within a device much more efficiently than conventional optical fibers. Yet another (ORCHID) successfully demonstrated the "squeezing" of light, a concept in quantum optics that can ultimately lead to dramatic performance gains in microsystems. These programs challenge the assumption that highly specialized, high-precision systems must be large and expensive.

Miniaturization with National Security Implications

Other advances in miniaturization include a recent demonstration by DARPA-funded researchers of the world's smallest vacuum pumps. This breakthrough technology may create new national security applications for electronics and sensors that require a vacuum: highly sensitive gas analyzers that can detect chemical or biological attack, for instance, or extremely accurate laser-cooled chip-scale atomic clocks and microscale vacuum tubes. As part of another program (QuASAR), one which seeks to exploit the extreme precision and control of atomic physics for new sensor technology, researchers have developed methods for measuring magnetic fields at scales smaller than the size of a single cell. Applications include critical advances in position, timing and navigation—all critical to military situational awareness and operations.

Ground Robotics

Some advances seem much closer to our doorstep than they really are—thanks to science fiction and the amazing special effects of creative individuals and teams who lead our entertainment industry. Ground robotics is one such domain. At the DARPA Robotics Challenge trials a few months ago, we drove robotics technology forward by engaging teams of creative specialists at companies, universities and other government agencies. These world-leading experts were charged with advancing the capabilities of robots to perform basic skills that would be required in carrying out humanitarian and disaster relief missions. The Robotics Challenge—which is still underway—is showing how robotics capabilities can advance. It is also demonstrating just how far these kinds of robots are from serious battlefield application. That, too, is part of DARPA's mission: push the research frontiers of what is possible and inform our military decision makers where those limits are and the prospects for the future.

Algorithms Opening New Horizons

Research in mathematical algorithms is also creating important new technological opportunities. Clustering algorithms can detect common activity patterns across a vast data set. A combination of vector mathematics, time integration, and power law distributions enables the analysis of ensemble behaviors—patterns that only become visible when correlated across large numbers of points. Time series analysis can find previously unknown outliers in a data set for anomaly detection. Our programs apply these mathematical techniques to immense data sets with hundreds of millions or even many billions of elements. Individually or in combination, these new algorithmic approaches enable rapid analysis of data volumes that finally begins to scale with the complexity of the national security challenges that we face today.

I have cited several examples of DARPA technologies that made significant progress in the last year. There are many more in that same category. Additional examples of successes in the making are attached to my testimony.

THE PRESIDENT'S FISCAL YEAR 2015 BUDGET REQUEST

The President's fiscal year 2015 budget request for DARPA is $2.915 billion. This compares with $2.779 billion appropriated for fiscal year 2014, an increase of $136 million. Before describing our fiscal year 2015 plan, let me put this number in context.

From fiscal year 2009 to fiscal year 2013, DARPA's budget declined through a series of small reductions followed by the 8 percent across-the-board sequestration cut in fiscal year 2013. The total reduction to DARPA's budget from fiscal year 2009 to fiscal year 2013 was 20 percent in real terms.

This pernicious trend turned around last year. I thank this Subcommittee, and Congress more broadly, for your support in helping us to begin to address this issue in fiscal year 2014 by restoring an initial $199 million. The President's fiscal year 2015 request continues restoration, almost returning the Agency's budget to its pre-sequestration level in real terms.

Let me outline what these budget changes mean in terms of our ability to execute DARPA's vital mission. As budgets eroded over the last few years, one effect was a reduction in our major demonstration programs. In some cases, we have been unable to advance our work to the point of actually demonstrating that a totally new approach is workable. In other cases, we had to rely on a single approach to solving a particularly challenging problem because we could fund only one performing organization. That is especially problematic since we are trying to do things that have never been achieved before. Reduced funds also meant fewer early-stage investments to explore new research frontiers. Sequestration further affected our programs, with many being delayed or reduced.

In the current fiscal year, the partial restoration of funds is making a real difference in DARPA's ability to attack the thorny problems the Nation faces in today's military and national security environment. As a projects agency, DARPA is always beginning new programs as old ones end. But the new efforts in fiscal year 2014 are stronger because of the healthier budget level. In some areas, we are now able to plan for the real-world prototyping and field testing needed for new concepts to be fully evaluated. And our new programs include the important exploratory projects that will expand future national security opportunities. The fiscal year 2015 request before you today will allow us to continue to restore and strengthen our portfolio of investments. With this funding level, we will be on the right track.

Let me close by saying that I am mindful of the challenges that our Nation faces and the increasingly difficult environment in which we work, including severe constraints on resources. But I also am excited about what lies ahead and confident that—with your support for the President's fiscal year 2015 budget request—DARPA will continue to make a real and outsized difference in redefining the national security landscape and our Nation's security.

Again, thank you for your support—past, present, and future. I look forward to working with you, and will be pleased to respond to your questions.

ADDENDUM

DARPA Transitions

Many technologies from earlier DARPA investments are now moving forward with a wide variety of our partners and customers. These summaries provide snapshots of progress for some programs from recent years.

Leap Ahead in Surface Warfare Capabilities by Reducing Dependence on ISR Platforms, Network Links, and GPS: Long Range Anti-Ship Missile (LRASM)

Technology Description and Program Goal

—Our current anti-ship missiles must penetrate sophisticated enemy air defense systems from long range. As a result, Warfighters may require multiple missile launches and overhead targeting assets to engage specific enemy warships from beyond the reach of counter-fire systems. To overcome these challenges, the DARPA-Navy Long Range Anti-Ship Missile (LRASM) program is investing in advanced technologies to provide a leap ahead in U.S. surface warfare capability.

—LRASM aims to reduce dependence on intelligence, surveillance and reconnaissance (ISR) platforms, network links, and GPS navigation in electronic warfare environments. Autonomous guidance algorithms should allow LRASM to use less-precise target cueing data to pinpoint specific targets in the contested domain. The program also focuses on innovative terminal survivability approaches and precision lethality in the face of advanced countermeasures.

—LRASM began in 2009. Now in its final DARPA phase, this program leverages the state-of-the-art Joint Air to Surface Standoff Missile Extended Range (JASSM-ER) airframe and incorporates additional sensors and systems to achieve a stealthy and survivable subsonic cruise missile.
—In 2013, DARPA conducted two flight demonstrations, each with resounding success. The LRASM was dropped from an Air Force B-1, successfully separated from the aircraft, navigated through a series of preplanned waypoints, and then transitioned to an autonomous mode while seeking the target it had been instructed to attack. The missile detected, identified, and tracked the mobile ship target at extended range; transitioned to guidance on the terminal sensor; and impacted the target with a miss distance well within acceptable error probabilities. Other flight achievements include weapon data link updates, transmission of weapon in-flight tracks, and increased flight range.

Transition Plan and Status

—The program is on track to deliver an advanced prototype weapon to the Navy and Air Force with capability for challenging future operational environments, while being sufficiently mature to transition rapidly to an acquisition program to address near-term operational challenges.
—DARPA is engaged with the U.S. Navy NAVAIR's Program Executive Office for Unmanned Aviation and Strike Weapons (PEO U&W) to provide an innovative management approach for rapid acquisition of LRASM for Air Force and Navy air launch platforms to meet offensive anti-surface warfare missions. This approach leverages DARPA investment, program security, contracts, and infrastructure. Ultimately, it will leverage DARPA's technology development and risk reduction efforts to expeditiously field LRASM. In fiscal year 2014, DARPA and Navy efforts include continued technology development, integration risk reduction, and pre-Milestone B activities.
—DARPA has transitioned the technology to a new DARPA/Navy/Air Force co-staffed office chartered by USD(AT&L) to rapidly deploy this dramatically enhanced new capability.

Reducing Drag and Fuel Usage: Formation Flight for Aerodynamic Benefit

Technology Description and Program Goal

—With the Air Force consuming more than 2.5 billion gallons of aviation fuel in 2010, DARPA launched the Formation Flight for Aerodynamic Benefit program to seek creative ways to reduce drag and fuel usage in the C-17 fleet.
—C-17s are the largest single user of aviation fuel, consuming 650 million gallons (26 percent) in 2010. DARPA's goal was to achieve a 10 percent reduction in fuel flow.
—The approach taken was motivated by large flocks of migratory birds that fly in a "V" formation.
—All aircraft produce wingtip vortices when flying, which are a drag byproduct of producing aerodynamic lift. After analyzing C-17 wingtip vortices, DARPA predicted optimum formation positions.
—The DARPA program created new software that innovatively enabled precise autopilot and auto-throttle formation flight operations with existing C-17 hardware.
—DARPA simulation, modeling, and lab testing projected success in reaching the target reduction in fuel flow using this software modification.

Transition Plan and Status

—DARPA transitioned the software to the Air Force Research Laboratory (AFRL) in July 2012 as the Surfing Aircraft Vortices for Energy ($AVE) program.
—AFRL conducted 30 hours of flight testing in C-17 formation flight, including 12 hours on operational flight routes over the Pacific in 2013.
—That testing validated a 10 percent fuel flow reduction with the DARPA software modification. Moreover, the changes were safe, aircrew friendly, and aircraft friendly—and made business sense.
—The Applied Technology Council approved funding for an Advanced Technology Demonstration (ATD) of the DARPA C-17 software-only modification. The ATD will enable the Air Mobility Command to develop CONOPS for rapid fielding this DARPA energy efficiency advancement.
—AFRL is examining use of this technology to obtain fuel savings on C-130s and other DOD platforms.
—Commercial carriers, the Federal Aviation Administration, and the National Aeronautics and Space Administration (NASA) expressed interest in civilian applications of this DARPA technology.

—This DARPA program success reflects significant contributions from the Air Mobility Command, AFRL, 412th Test Wing, Air Force Life Cycle Management Center, Boeing Company, and NASA Neil A. Armstrong Flight Research Center.

New Approaches to Tackling DOD's Language Challenges: BOLT, RATS, and MADCAT

Technology Description & Program Goal

—DARPA has invested in solutions for DOD to recognize, classify, and help digest written and spoken foreign languages.

—Technology from the Broad Operational Language Translation (BOLT) program provides automated translation and linguistic analysis that can be applied to informal genres of text and speech as well as multilingual search capability and unrestricted multi-turn bilingual conversation.

—The Robust Automatic Transcription of Speech (RATS) program creates algorithms and software to perform the following tasks on potentially speech-containing signals received over channels that are extremely noisy and/or highly distorted: speech activity detection, language identification, speaker identification, and keyword spotting in foreign languages.

—The Multilingual Automatic Document Classification Analysis and Translation (MADCAT) program automatically converts foreign language text images into English transcripts, eliminating the need for linguists and analysts while automatically providing relevant, distilled actionable information to military command and personnel in a timely fashion.

BOLT Transition Plan and Status

—The Combating Terrorism Technical Support Office (CTTSO), under the Assistant Secretary of Defense for Special Operations/Low-Intensity Conflict, successfully transitioned to military users a tool for translation of and topic spotting and data exploitation in social media. Initial implementation is with a military user with plans to extend use to multiple government, military, and academic media monitoring system users.

RATS Transition Plan and Status

—The Air Force has provided lab facilities to test RATS capability using operational data. Initial evaluations show RATS technology superior to any other system, and plans are underway for integrating the speech activity detection portion of the RATS technology into systems that provide noisy speech signal processing capabilities. Other interested DOD elements are awaiting the results of operational field trials before pursuing acquisition.

MADCAT Transition Plan and Status

—MADCAT optical character recognition has been coupled with machine translation and deployed in 11 languages to enable English-speaking government and military personnel to read hardcopy foreign language documents. A project also is underway to further develop Korean optical character recognition and machine translation to support user requirements.

—MADCAT offline handwriting recognition system was delivered to a government user in 2011 and is in operational use. The CTTSO is supporting the MADCAT transition to various other DOD and intelligence community users.

Achieving Dramatically Faster Mapping: High-Altitude LIDAR Operations Experiment (HALOE)

Technology Description and Program Goal

—Leveraging past DARPA developments in Light Detection and Ranging (LIDAR) systems, a sensor pod for rapid collect, wide area, long range, high-resolution 3D datasets was developed for the HALOE system. In 2010 and 2011, DARPA invested funds to harden the sensor system in preparation for a prolonged operational trial in Afghanistan.

—HALOE provided forces in Afghanistan with unprecedented access to high-resolution 3D data, and it collected orders of magnitude faster and from much longer ranges than conventional methods. At full operational capacity, HALOE could enable mapping of 50 percent of Afghanistan in 90 days. State-of-the-art deployed systems would have required 3 years to accomplish that task, and more conventional systems would have required 30 years.

—This increased performance is enabled by advances in shortwave infrared sensitive material properties that permitted photon-counting detector arrays so sensitive that it is now possible to make range measurements with fewer than 10 photons received, versus tens of thousands of photons. As is true with any

camera, increased sensitivity means an image can be captured more quickly since the shutter has to be open for less time—and less light is required to capture an image. Less time and less power translate to higher collection rates at greater standoff. HALOE can collect data at a rate more than 10 times faster than state-of-the-art systems or 100 times faster than conventional systems.

—HALOE was one of several DARPA advances directly supporting the Warfighter that earned the agency the Joint Meritorious Unit Award from the Secretary of Defense late in 2012.

Transition Plan and Status

—The HALOE sensor pod was initially integrated onto a WB-57 aircraft and deployed to Afghanistan from November 2010 through August 2011 in a joint effort with the Army Geospatial Center (AGC). During this time, over 70,000 square kilometers of terrain data (about 10 percent of Afghanistan) were collected, reflecting the priorities of operational units.

—In March 2012, with AGC funding, the HALOE sensor pod was integrated onto a BD700 aircraft, a highly customized, longer-range flight platform.

—In July 2013 the HALOE system was deployed to the AFRICOM Area Of Responsibility (AOR). The system collected data in Africa during eight flight sorties through August.

—In September 2013, HALOE was transferred to Afghanistan in September 2013.

—HALOE performed exceedingly well in its several deployments in Afghanistan, collecting more than 83 percent of all tasked regions with a cumulative mission area of greater than 74,000 square kilometers. The collected data have been in response to multiple RFIs in support of operational units. The HALOE system has transitioned out of theater, with the last sortie flown in December 2013.

—Plans call for a 6-month period in CONUS for maintenance and training followed by redeployment in June 2014 for the remainder of fiscal year 2014. Potential locations include AOR of USCENTCOM (not Afghanistan), USAFRICOM, and USPACOM.

Blast Monitoring Tool Also Will Improve Future Understanding of Injuries: Blast Gauge

Technology Description and Program Goal

—Blast Gauge is a low-cost, disposable, individually wearable sensor system that records the environment during an explosive event—for example, an attack from an improvised explosive

device (IED) or a rocket-propelled grenade (RPG), or the firing of a missile or rocket during training.

—The goal was to rapidly develop and field a system to quantify blast exposure, assist commanders in finding injured Service Members who would otherwise not report, and record data to understand blast injuries, including traumatic brain injury (TBI).

—DARPA recognized that blast overpressure and linear acceleration must be recorded—and at multiple points on the body—to understand blast-related injuries and that the needed technology could be built completely out of common commercial components.

—The device was developed in just 11 months; Special Operations Forces (SOF) fielded Blast Gauge in Afghanistan in July 2011 and Rochester Institute of Technology researchers who developed the dosimeter quickly formed a small business to commercialize and manufacture the gauges.

—Costing less than $50 per device, the gauge includes a simple three-light system (red, yellow, green) to indicate condition and magnitude immediately following a blast. Service Members wear three gauges: on the back of the helmet, shoulder, and chest. This allows a blast to be captured regardless of its relative location.

—Information is transmitted to medical staff and researchers; doctors and medics report that the lights are a valuable feature for augmenting triage following a blast.

—DARPA also developed a system to capture the data, contributing to better understanding of the effects of blasts on the brain.

Transition Plan and Status

—DARPA completed development with release of the latest generation gauge in June 2013. It can be purchased directly from the manufacturer or from Defense Logistics Agency stock.

—DARPA initially provided field support to train Soldiers on the gauges and to distribute gauges and collect exposure data. More than 150,000 gauges (50,000 sets) have been distributed to all Services.
—As a result of the DARPA-funded field trials, Blast Gauge technology has been adopted by SOF and the Army:
  —The Combined Joint Special Operations Task Force Afghanistan (CJSOTF-A) mandated that all special operators in its task forces use blast gauges. They are purchasing 60,000 gauges for deployed forces and stateside training.
  —Other SOF units are purchasing and using gauges throughout training and operations. In these cases, Blast Gauge has become a key component of their strategy for managing TBI.
  —The Army has selected Blast Gauge as one of three components of its Integrated Soldier Sensor System (ISSS) requirement. DARPA is supporting the Army in designing and evaluating the ISSS.
  —While the Army is developing its objective solution (ISSS), it selected the Blast Gauge to be fielded to 18,000 Soldiers in OEF.
—Other services (including the Marine Corps Warfighting Laboratory), NATO partners, and Australia have independently evaluated the gauges and are deciding on next steps.
—Blast Gauge was cited as a DARPA advance directly supporting the Warfighter that contributed to the agency being awarded the Joint Meritorious Unit Award from the Secretary of Defense in 2012.
—Military officials have shown interest in examining the data and post-event analyses to gain insights into potential issues with brain injuries resulting from improper techniques and procedures for using equipment, including during training when most exposures occur.

Revolutionizing Prosthetics (RP): Restoring Near-Natural Movement and Control of Upper Limbs

Technology Description and Program Goal

—When DARPA launched the Revolutionizing Prosthetics (RP) program in 2006, the state of upper-limb prosthetic technology was far behind lower-limb technology and was judged to be a more difficult medical and engineering challenge.
—The concept of a new system design may open the option for Service Members and others with upper-limb loss the chance to return to more fully active lives.
—The two research teams selected for the program, DEKA Integrated Solutions Corporation and the Johns Hopkins University Applied Physics Lab (APL), were tasked to:
  —Design and build anthropomorphic electromechanical upper extremity prostheses that mimic the capabilities of a natural arm for people with loss of an upper-limb.
  —Develop near-natural control modalities including exploration of direct neural control from peripheral nerves or the brain.
  —Investigate the ability to provide sensory feedback from sensors on the prosthesis through peripheral nerves or directly to the brain.
—Collaboration with Veterans Affairs, National Institutes of Health, Army Medical Research and Materiel Command, and Walter Reed National Military Medical Center has given more than75 users (amputees and tetraplegics) an opportunity to provide input to the design of both arm systems and supported regulatory submissions. In addition, Revolutionizing Prosthetics became the pilot program of the Food and Drug Administration's Innovation Initiative in 2011, providing a new pathway for novel medical technologies.

Transition Plan and Status

—Since February 2012, the University of Pittsburgh Medical Center, a subcontractor to the Applied Physics Lab (APL), has conducted a successful clinical study in which research participants living with tetraplegia were able to use neural signals from their brain to directly control the Modular Prosthetic Limb (MPL). This work has demonstrated that advanced prosthetics and direct neural interfaces can enable restoration of near-natural arm control to improve the quality of life for military personnel and civilians living with amputation or paralysis.
—Veterans Affairs is conducting an independent 3-year home study of the DEKA Arm System. The Food and Drug Administration's May 2014 approval allows DEKA to pursue manufacturing and commercial opportunities to bring the arm to market. Their transition plan includes development of advanced manufacturing and distribution to medical practitioners.

—The APL's MPL serves as a research platform and some MPL technology has transitioned to small robotic systems used in manipulating unexploded ordnance and suspicious objects.

Smartphone Apps for the Dismounted Warfighter: Transformative Apps (TransApps)

Technology Description and Program Goal

—Today's Warfighters perform increasingly complex tasks but are still using outdated tools to access and share information on the battlefield. From a ground Soldier's perspective, little has changed in the last 20 years. They rely on inferior paper maps, written notes and reference materials, and voice radio transmissions to carry out their missions. Many technology advances that consumers take for granted have not made their way to the battlefield for a variety of reasons, especially security concerns and lack of robust high-bandwidth networks.
—With the TransApps program, DARPA aims to put today's commercial smartphone-grade capabilities in the hands of the Soldiers who most need them—those on daily patrols in theater—making their work much more effective and their lives easier and safer. In the field, the devices are providing Soldiers with an integrated ecosystem for situational awareness.
—Soldiers on patrol can keep up with fast-paced missions and changing environments by sharing and managing information in real time. That allows Warfighters and decision makers up and down the ranks and in various functions to share a common operating picture.
—They do this by using features and apps designed for their unique requirements: for example taking note of changes in the field—such as new bridges, structures, or civilians in an area—and sharing that information immediately with others who will direct and carry out future operations in that area.
—TransApps created a new agile development process, integration framework, and customized test cycles to allow rapid development of new applications, with new features and enhancements deployed quickly based on Soldiers' evolving requirements. When Soldiers need new apps, they can get them quickly—sometimes the very next day. This is a radical departure from how they have been operating. The TransApps ecosystem bridges old and new, allowing future technologies to work seamlessly with legacy radios and information systems. By endowing commercial off-the-shelf (COTS) smartphones with custom multilayered security and agile development processes modified for the tactical community, TransApps is creating a scalable and sustainable infrastructure template.

Transition Plan and Status

—A 4-year program that concludes in fiscal year 2014, TransApps was first fielded to Afghanistan in 2011; within 18 months, more than 3,000 systems were deployed to the battlefield, supporting all Army maneuver operations theaterwide.
—In fiscal year 2014, DARPA is working with the Army Nett Warrior Program to fully transition TransApps capabilities into the enduring Program of Record, as part of the Army's efforts to get new technologies into the hands of the Soldier.
—Other organizations and agencies are preparing to transition program components. These include the Application Testing Portal for streamlined security and performance analysis of mobile applications, as well as TransApps' custom imagery processing and configuration tools, which empower Soldiers to manage their own maps based on mission requirements.

Persistent Close Air Support: Faster and There When Troops Need It

Technology Description and Program Goal

—To maintain a decisive tactical advantage in 21st-century combat, Warfighters need to safely, rapidly, and collaboratively deploy ordnance against elusive mobile targets. Unfortunately, air-ground fire coordination, referred to as Close Air Support, or CAS, has changed little since World War I.
—Pilots and dismounted ground agents can focus on only one target at a time and often must ensure they hit it using just voice directions and a paper map. In complex environments, it can take up to an hour to confer, get in position and strike—time in which targets can attack first or move out of reach.
—DARPA created the Persistent Close Air Support (PCAS) program to enable dismounted ground agents and combat aircrews to share real-time situational awareness and weapons systems data.
—The system DARPA developed and tested enables ground agents to quickly and positively identify multiple targets simultaneously. Ground and air forces would

jointly select precision-guided ordnance that best fits each target and minimizes collateral damage and friendly fire.

Finally, both parties would authorize weapons deployment.

—Benefits would include reduction in time from calling in a strike to target hits reduced from as much as 60 minutes to just 6 minutes; direct coordination of airstrikes by a ground agent from manned or unmanned air vehicles; improved speed and survivability of ground forces engaged with enemy forces; and use of smaller, more precise munitions against smaller and moving targets in degraded visual environments. Another benefit is graceful degradation; if one piece of the system fails, Warfighters still retain capability of more basic functionality.

Transition Plan and Status

—In early 2013, DARPA deployed 500 Android tablets equipped with PCAS-Ground situational awareness software to units stationed in Afghanistan. An operator on the ground—with a tablet and voice radio—communicated with a pilot who had a tablet in the cockpit about imagery they both share on their tablets. (The program also developed a networked solution that allows even more rapid information sharing.)

—Field reports show that PCAS-Ground replaced those units' legacy paper maps, dramatically improving ground forces' ability to quickly and safely coordinate air engagements.

—The program, which began in fiscal year 2010 and concludes in early 2015, is in the flight-testing phase, which concludes with live fire demonstrations.

—Elements of PCAS, particularly the JTAC ground software, are seeing traction among various JTAC-related programs of record across the Services.

Senator DURBIN. Thank you.

Dr. Rauch.

STATEMENT OF DR. TERRY RAUCH, DIRECTOR, MEDICAL RESEARCH FOR THE ASSISTANT SECRETARY OF DEFENSE

Dr. RAUCH. Chairman Durbin, Vice Chairman Cochran, members of the committee, I would like to thank you for the opportunity to appear before you to discuss our research within the military health system and our collaborations across Government, academia, and industry.

IMPROVEMENTS IN COMBAT CASUALTY CARE

The military health system is a complex enterprise that we use to gather health care delivery, medical education, public health, private sector partnerships and cutting edge research. Our research is the engine to integrate and embed emerging evidence-based practices into a learning healthcare system where healthcare providers, scientists, patients participate in the generation of knowledge on health outcomes, identifying and evaluating best medical practices, and assessing the impact of changes in medical practice.

Research in the military health system has played a significant role in changing health outcomes over the last 13 years of war. As the war progressed, the case fatality rate of our servicemembers was nearly cut in half, and remarkably, this occurred when the severity of injuries were increasing. Today we deliver the highest survivability rates in the history of warfare and that survivability is coupled with greater post-injury quality of life. This is a tribute to our learning healthcare system.

PREVENTION, CARE, AND TREATMENT OF POST-TRAUMATIC STRESS DISORDER AND OTHER PSYCHOLOGICAL HEALTH ISSUES

Many of the results stemming from our research have not only contributed to the survival and recovery of U.S. servicemembers, but also translates well into the civilian setting. Similar to the military experience, the results of military medical research translate into improved hemorrhage control, resuscitation en-route care, and damage control surgery in the civil setting. Although significant and continuing improvements in combat casualty care and personal equipment have reduced fatal injuries, many servicemembers return home with traumatic brain injury, post-traumatic stress disorder (PTSD), suicidal thoughts or behaviors, and other co-occurring conditions such as depression, substance abuse related to alcohol, tobacco, and other drugs, including misuse and abuse of prescription drugs, and of course, chronic pain. All of these complicate the prevention and treatment of PTSD, traumatic brain injury, and suicidal behaviors.

To improve the prevention, diagnosis, and treatment of mental health conditions affecting veterans and servicemembers and military families, the President issued an Executive order in 2012 and directed the Federal agencies to develop a coordinated national research action plan. The Department of Defense with the VA and HHS (Department of Health and Human Services) and the Department of Education responded with a wide-reaching plan to improve scientific understanding, provide effective treatment, and reduce the occurrences of PTSD, traumatic brain injury, various co-occurring conditions, and suicide. The plan builds on substantial work already underway in the Federal agencies and provides a framework for improved coordination across Government and in partnership with academia and industry to share information, brainstorm innovations, and accelerate science.

PREPARED STATEMENT

Scientific progress is incremental. It takes time, but our servicemembers and their family members need more effective prevention strategies and treatments. So our research mission is urgent, most urgent.

I am both pleased and proud to be here today to represent the women and men who perform the research mission of the military health system, and I look forward to answering your questions.

[The statement follows:]

PREPARED STATEMENT OF DR. TERRY M. RAUCH

Mr. Chairman, Members of the Committee, thank you for the opportunity to appear before you today to discuss medical research in the Military Health System (MHS) and, in particular, our research collaborations across government, academia, and industry.

The MHS is a complex system that weaves together healthcare delivery, medical education, public health, private sector partnerships and cutting edge medical research. Research in the MHS is the engine to integrate and embed emerging evidenced-based practices into a learning healthcare system in which the healthcare providers, scientists, systems, and patients participate in the generation of knowledge on trends in health and illness, the testing and identification of best practices, and the assessment of the impact of practice changes.

Research by the MHS has played a significant role in the performance of military trauma care over the last 13 years of war. As the war progressed, we improved sur-

vivability rates—although the severity of injuries increased. Today, we deliver the highest survivability rates in the history of warfare and that survivability is coupled with greater post-injury quality of life. These notable achievements reflect the return on investment by MHS research in combat casualty care, traumatic brain injury (TBI), psychological health and suicide, rehabilitation and regenerative medicine, military operational medicine, military infectious diseases, and medical training and simulation. I will highlight achievements in some of these areas as well as our collaborations across government, academia and industry.

COMBAT CASUALTY CARE RESEARCH

Accomplishments in combat casualty care have led to the fielding of safe and effective tourniquets, improved hemostatic dressings, as well as numerous clinical practice guidelines to improve trauma care on the battlefield. A significant enabler in these accomplishments is the Joint Trauma System or JTS which has developed into the Department of Defense's (DOD) "go-to" entity for real-time process improvement to optimize survival and recovery of the warfighter. The swift translation of evidence from military research through the JTS to the battlefield represents a first in military medical history. The JTS maintains the Department of Defense Trauma Registry (DODTR) which is the largest repository of combat injury and trauma management information in history. In this capacity, the JTS and the process it supports serve as a fitting "bedside" to generate many of the clinical questions that need answers from military medical and trauma research.

Recently, MHS researchers collaborating with industry received Food and Drug Administration approval for a hemostatic device for the control of bleeding from junctional wounds in the groin or axilla not amenable to tourniquet application. In addition, the MHS is conducting advanced development efforts on a dried plasma product to help control hemorrhage on the battlefield. Other research efforts investigate genetic, genomic, and immunological responses to trauma and hemorrhage and finding improved means to reduce hypothermia.

DOCUMENTING AND SHARING LESSONS LEARNED

Advances in trauma care stemming from the military's learning health system have been accelerated by the unprecedented burden of injury resulting from the wars in Afghanistan and Iraq. While the more than 30 Clinical Practice Guidelines maintained by the JTS are evidence based, they are also responsive and practical. Reports on the translation of advances in military trauma care to the civilian community have become increasingly common. We are taking intentional steps to codify and garner the lessons within the military's learning healthcare system and promote their translation to the civilian sector in partnership with the Institute of Medicine.

VACCINE RESEARCH

As a final step towards FDA licensure in the United States, a clinical trial of a third generation smallpox vaccine, already approved in Europe and Canada, is about to start in U.S. forces stationed in South Korea. The DOD is participating in the clinical trial with the vaccine manufacturer and has designated a staff member from the U.S. Army Research Institute of Infectious Diseases to serve as the DOD principal investigator. The new product is a modern smallpox vaccine that does not replicate in human cells and is expected to be a safe alternative for individuals who have certain contraindications to the current smallpox vaccine.

NATIONAL INTERAGENCY BIODEFENSE CAMPUS

The National Interagency Biodefense Campus (NIBC) is a prime example of interagency collaboration and includes not only DOD, but the HHS' National Institute of Allergy and Infectious Diseases, the Centers for Disease Control and Prevention, and the Departments of Agriculture (USDA) and Homeland Security (DHS). Key DOD components of the NIBC are the U.S. Army Medical Research Institute of Infectious Diseases and the U.S. Navy Medical Research Center. The NIBC is leading in the development of medical counter measures as well as enhancing the U.S. response to emerging threats and national emergencies and is one of the Nation's few laboratory centers with Biosafety level 3 and 4 laboratories conducting world class research against the world's most dangerous pathogens such as viral hemorrhagic fevers and plague. The NIBC is a part of the larger interagency confederation known at the National Interagency for Biological Research (NICBR).

U.S. ARMY MEDICAL RESEARCH INSTITUTE OF CHEMICAL DEFENSE

With your support the DOD has invested significantly in the U.S. Army Medical Research Institute of Chemical Defense (MRICD) with a recapitalization project. The MRICD is currently at the 95 percent stage of construction completion for a new Command and state of the art laboratory building. They are scheduled to occupy the new building in early January 2015. The MRICD is the Nation's Center of Excellence for medical chemical defense research. Their world renowned scientists conduct basic and applied research on the mechanisms of action of chemical warfare threat agents, toxic industrial chemicals, and toxins of biological origin. These hazardous chemicals and toxins endanger not only our deployed our military forces but also pose an extremely serious homeland security threat to our entire civilian population as recent events in the Middle East have shown. The MRICD operates on a whole of government approach by being the premier laboratory to research candidate pretreatment, prophylactic, and treatment compounds. These compounds establish a scientific and technical base from which to plan and formulate enhanced medical countermeasures for our entire population. Their efforts have produced many candidates for transition into the advance development arena. Their scientists are on point to investigate medical countermeasures for all non-traditional agents as well as any emerging chemical threat agent regardless of the source. The MRICD also provides consultative subject matter expertise on medical chemical defense issues. They educate and train the full spectrum of military/civilian first responders and medical professionals in the identification and management of chemical casualties. Many of our allied partners have recently sent personnel to be trained in their courses so they can treat chemical casualties no matter the circumstances.

REHABILITATION AND REGENERATIVE MEDICINE RESEARCH

Due to advances in combat casualty care, increasing numbers of Service members are surviving with extreme trauma to the extremities and head. Research by the MHS in rehabilitation and regenerative medicine focuses on definitive and rehabilitative care innovations required to reset Service members, both in terms of duty performance and quality of life. The program has multiple initiatives to achieve its goals, including improving prosthetic function, enhancing self-regenerative capacity, improving limb and organ transplant success, creating full functioning limbs and organs, repairing damaged eyes, treating visual dysfunction following injury, improving pain management, and enhancing rehabilitative care. Innovative reconstructive research supported by the MHS in partnership with Brigham and Women's Hospital has performed successful face transplants on patients with severe facial deformity to provide functional and aesthetic benefits. In addition, research supported by the MHS in partnership with Johns Hopkins Hospital performed a bi-lateral hand transplant on a Service member who lost all four limbs from a road side bomb in Iraq. Today that Service member has achieved significant function in both hands. Regenerative medicine technologies present many opportunities for the treatment of combat-related traumatic injury and the MHS is supporting the Armed Forces Institute of Regenerative Medicine-Warrior Restoration Consortium to position promising technologies and therapeutic/restorative practices for entrance into human clinical trials. The Warrior Restoration Consortium is a partnership with more than 30 academic institutions and industry partners to address five focus areas in: extremity regeneration; craniomaxillofacial regeneration; skin regeneration; genitourinary/lower abdomen reconstruction; and composite tissue allotransplantation (i.e., organ transplant from a donor) and immunomodulation or modification of the immune response.

RESEARCH TO IMPROVE MENTAL HEALTH FOR SERVICE MEMBERS AND MILITARY FAMILIES: THE NATIONAL RESEARCH ACTION PLAN

Although significant and continuing improvements in combat casualty care and personal protective equipment have limited fatal injuries, many Service members return with TBI, Post Traumatic Stress Disorder (PTSD), suicidal thoughts or behaviors, and comorbidities. These comorbidities include depression; substance abuse related to alcohol, tobacco, and other drugs, including the misuse and abuse of prescription drugs; and chronic pain, all of which can complicate the prevention and treatment of PTSD, TBI, and suicidal behaviors. Family members also are affected by the multiple stressors associated with deployment and reintegration. Overall, the need for mental health services for Service members and their family members is anticipated to increase in coming years.

To improve prevention, diagnosis, and treatment of mental health conditions affecting veterans, Service members, and military families, the President issued an

Executive Order in 2012 directing Federal agencies to develop a coordinated National Research Action Plan (NRAP). The Departments of Defense, Veterans Affairs, Health and Human Services, and Education responded with a wide-reaching plan to improve scientific understanding; provide effective treatment; and reduce occurrences of PTSD, TBI, various co-occurring conditions, and suicide.

The NRAP, released in August 2013, is a strategic blueprint for interagency research to identify and develop more effective diagnostic and treatment methodologies to improve outcomes for TBI, PTSD, and related conditions as well as develop and test suicide risk assessments and suicide prevention and treatment interventions. These efforts include collaborative research on biomarkers to detect disorders early and accurately; safe and effective treatments to improve function and quality of life; and developing a more precise definition of mTBI. The NRAP includes clear timelines and goals to achieve the same level of urgency, specificity of deliverables, as well as accountability, as expressed in the Executive Order. It is important to note that improving mental health outcomes for Service members and Veterans and the NRAP are included in the newly-established Cross-Agency Priority Goal framework overseen by the Office of Management and Budget and the Performance Improvement Council. The Cross-Agency Priority Goal, Improving Mental Health Outcomes for Service members and Veterans, was announced on March 10, 2014, and will continue over a 3 year period. Leadership will report quarterly to the Office of Management and Budget on their progress under the Goal.

Critical to the implementation of the NRAP is a continuing understanding of the agency-specific activities and assuring a collaborative and integrated research strategy to meet the requirements in the NRAP. This collaboration and integration is provided in an annual Joint Review and Analysis meeting on research related to PTSD, TBI, suicide prevention, and substance abuse. Agency representation at the meeting included DOD, the Department of Veterans Affairs (VA), the Department of Education (represented by the National Institute on Disability and Rehabilitation Research [NIDRR]), and Health and Human Services (represented by the National Institute of Neurological Disorders and Stroke, the National Institute of Mental Health, and the National Institute on Drug Abuse).

MHS researchers are attempting to answer questions across the research continuum. However, fundamental gaps in scientific knowledge remain, such as: the lack of a clinically-useful definition for mild TBI (mTBI)/concussion makes it difficult to adequately diagnose this condition. Note mTBI and concussion are used interchangeably herein. For mTBI, improved techniques are needed to determine if symptoms are attributable to the traumatic event. Prevention and treatment interventions are needed that address the comorbidities that often occur with PTSD. Evidence-based approaches are limited for reducing suicide risk, and the relationships between PTSD, TBI, suicide, and co-occurring conditions are not well understood.

Activities are underway in support of inter-agency collaboration, including the DOD's Systems Biology Program and the Millennium Cohort and Family Cohort Studies, the VA's Million Veteran Program, the National Institutes of Health (NIH) biomarker research program, and research dedicated to advancing prevention and treatment interventions. The DOD and the Centers for Disease Control are partnering with the Brain Trauma Foundation to develop a clinically useful definition of mTBI/concussion. Suicide prevention research includes the DOD's Military Suicide Research Consortium and the National Institute of Mental Health and DOD Army Study to Assess Risk and Resilience in Service members (Army STARRS) program.

Data-sharing efforts include the DOD/NIH Federal TBI Research Informatics System for TBI clinical research (a central repository for new TBI-related data that links to existing databases to facilitate sharing of information), the VA computing infrastructure, and NIDRR's TBI Model Systems National Database, which contains retrospective data on the clinical progress and outcomes of individuals with moderate to severe TBI.

Recently initiated activities include two new joint funded DOD and VA research consortium efforts with academia to support PTSD and TBI biomarker studies. The Consortium to Alleviate PTSD is a new research effort focused on biomarker discovery and development with the aim of identifying biomarkers for subacute and chronic PTSD that can be used for therapeutic and outcome assessment. This represents a major investment to advance knowledge related to biomarkers and clinical utility. The Chronic Effects of Neurotrauma Consortium will establish the association of the chronic effects of mTBI and common comorbidities; determine whether there is a causative effect of chronic mTBI/concussion on neurodegenerative disease and other comorbidities; identify diagnostic and prognostic indicators of neurodegenerative disease and other comorbidities associated with mTBI/concussion;

and develop and advance methods to treat and rehabilitate chronic neurodegenerative disease and comorbid effects of mTBI/concussion.

The MHS is funding a wide variety of studies relevant to military family members, including research focused on: understanding risk and resilience factors of military families and communities; suicide bereavement in Service members and their families; interventions to enhance resilience, address and prevent relationship problems, and support families during deployment; the effectiveness of web-enhanced support tools for military families; and the effects of military deployment of parents on adolescent mental health.

CONCLUSION

Scientific progress is incremental and takes time, but Service members and their family members need more effective prevention strategies and treatments, so our research mission is urgent. I am both pleased and proud to be here with you today to represent the men and women who perform the research mission of the MHS, and I look forward to answering your questions.

Senator DURBIN. Thank you very much.

Ms. Miller.

STATEMENT OF MARY MILLER, DEPUTY ASSISTANT SECRETARY OF THE ARMY FOR RESEARCH AND TECHNOLOGY

Ms. MILLER. Thank you, Chairman Durbin, Ranking Member Cochran, members of the committee. Thank you for this opportunity to discuss the Army's science and technology program for fiscal year 2015.

After 13 years of persistent conflict, the Army finds itself in a familiar situation, facing a declining defense budget and a strategic landscape that continues to evolve. As a result, the Army must balance between force structure, operational readiness, and modernization to maintain a capable force able to prevent, shape, and win in any engagement. Modernization will be slowed over the next 5 years. New programs will not be initiated as originally envisioned, and the Army's science and technology enterprise will be challenged to better prepare for the programs and capabilities of the future.

To ensure that we make the best choices for the future Army, we have established a comprehensive modernization strategy that facilitates, informs strategic decisions based on long-term objectives within a resource-constrained environment. This long-term look over 30 years was exceptionally powerful in facilitating the strategic decisions made within the Army as we built fiscal year 2015's President's budget. It allowed the Army leadership to make tough program decisions based on providing the most capability to the soldier, knowing that in some cases that meant delaying desired capabilities. This is essential as the Army looks at its S&T community to conduct more technology demonstration and prototyping initiatives that will focus on maturing technology, reducing program risk, defining realistic requirements, and conducting experimentation with soldiers to refine new capabilities and operational concepts. The S&T community will be challenged to bring forward not only new capabilities but capabilities that are affordable. They are up to this challenge.

PREPARED STATEMENT

We remain an Army that is looking towards the future while taking care of our soldiers of today. I hope that we can continue to

count on your support as we move forward. Thank you again for all that you do for our soldiers.

[The statement follows:]

PREPARED STATEMENT OF MARY J. MILLER

Chairman Durbin, Ranking Member Cochran, and distinguished members of the Subcommittee, thank you for the opportunity to discuss the Army's Science and Technology (S&T) Program for fiscal year 2015.

> "Over the past 12 years of conflict, our Army has proven itself in arguably the most difficult environment we have ever faced. Our leaders at every level have displayed unparalleled ingenuity, flexibility and adaptability. Our Soldiers have displayed mental and physical toughness and courage under fire. They have transformed the Army into the most versatile, agile, rapidly deployable and sustainable strategic land force in the world." [1] —*Secretary John W. McHugh, General Raymond T. Odierno*

After 13 years of persistent conflict, the United States finds itself in a familiar situation—facing a declining defense budget and a strategic landscape that continues to evolve. As our current large-scale military campaign draws down, the United States still faces a complex and growing array of security challenges across the globe as "wars over ideology have given way to wars over religious, ethnic, and tribal identity; nuclear dangers have proliferated; inequality and economic instability have intensified; damage to our environment, food insecurity, and dangers to public health are increasingly shared; and the same tools that empower individuals to build enable them to destroy." [2] Unlike past draw downs, where the threats we faced were going away, there remain a number of challenges that we still have to confront—challenges that call for a change in America's defense priorities. Despite these challenges, the United States Army is committed to remaining capable across the spectrum of operations. While the future force will become smaller and leaner, its great strength will lie in its increased agility, flexibility, and ability to deploy quickly, while remaining technologically advanced. We will continue to conduct a complex set of missions ranging from counterterrorism, to countering weapons of mass destruction, to maintaining a safe, secure and effective nuclear deterrent. We will remain fully prepared to protect our interests and defend our homeland.[3]

The Army depends on its Science and Technology (S&T) program to help prepare for the future, mitigate the possibility of technical surprise and ensure that we remain dominant in any environment. The Army's S&T mission is to foster discovery, innovation, demonstration and transition of knowledge and materiel solutions that enable future force capabilities and/or enhance current force systems. The Army counts on the S&T Enterprise to be seers of the future—to make informed investments now, ensuring our success for the future.

The Army is ending combat operations in Afghanistan and refocusing on the Asia-Pacific region with greater emphasis on responses to sophisticated, technologically proficient threats. We are at a pivotal juncture—one that requires us to relook the past 13 years of conflict and capitalize on all the lessons that we have learned, while we implement a strategic shift to prepare for a more capable enemy. As the Department of Defense prepares for the strategic shift, the Army will adapt—remaining an ever present land force—unparalleled throughout the World.

We are grateful to the members of this Committee for your sustained support of our Soldiers, your support of our laboratories and centers and your continued commitment to ensure that funding is available to provide our current and future Soldiers with the technology that enables them to defend America's interests and those of our allies around the world.

Strategic Landscape

As we built the fiscal year 2015 President's Budget Request, the Army faced a number of significant challenges. While the Army has many priorities, the first and foremost priority is and always will be to support our Soldiers in the fight. We are pulling our troops and equipment out of Afghanistan by the end of this December, we are drawing down our force structure, we are resetting our equipment after 13

[1] The Posture of the United States Army, Committee on Armed Services, United States House of Representatives, April 23, 2013.

[2] National Security Strategy, May 2010.

[3] "The Posture of the United States Army," The Honorable John M. McHugh, Secretary of the Army and General Raymond T. Odierno, Chief of Staff, United States Army before the Senate Committee on Appropriations, Subcommittee on Defense, May 22, 2013.

plus years of war and we are trying to modernize. Given the budget downturn within the Department of Defense, the Army has been forced to face some difficult choices. The Army is in the midst of a significant force structure reduction—taking the Army to pre-World War II manning levels. The Chief of Staff of the Army has undertaken difficult decisions balancing force structure, operational readiness, and modernization to maintain a capable force able to prevent, shape and win in any engagement. As a result, over the next 5 years, we face a situation where modernization will be slowed, new programs will not be initiated as originally envisioned and the Army's S&T Enterprise will be challenged to better prepare for the programs and capabilities of the future. We will focus on maturing technology, reducing program risk, developing prototypes that can be used to better define requirements and conducting mission relevant experimentation with Soldiers to refine new operational concepts. The S&T community will be challenged to bring forward not only new capabilities, but capabilities that are affordable for the Army of the future.

> "Going forward, we will be an Army in transition. An Army that will apply the lessons learned in recent combat as we transition to evolving threats and strategies. An Army that will remain the best manned, best equipped, best trained, and best led force as we transition to a leaner, more agile force that remains adaptive, innovative, versatile and ready as part of Joint Force 2020."[4] —*General Raymond T. Odierno, 38th Chief of Staff, Army*

Goals and Commitments

The emerging operational environment presents a diverse range of threats that vary from near-peer to minor actors, resulting in new challenges and opportunities. In this environment, it is likely that U.S. forces will be called upon to operate under a broad variety of conditions. This environment requires a force that can operate across the range of military operations with a myriad of partners, simultaneously helping friends and allies while being capable of undertaking independent action to defeat enemies, deter aggression, and shape the environment. At the same time, innovation and technology are reshaping this environment, multiplying and intensifying the effects that even minor actors are able to achieve.

The Army's S&T investment is postured to address these emerging threats and capitalize on opportunities. The S&T investment continues to not only focus on developing more capable and affordable systems, but also on understanding the complexity of the future environment. We have focused on assessing technology and system vulnerabilities (from both a technical and operational perspective) to better effect future resilient designs and to prepare countermeasures that restore our capabilities when necessary.

There are persistent (and challenging) areas where the Army invests its S&T resources to ensure that we remain the most lethal and effective Army in the world. As the Army defines its role in future conflicts, we are confident that these challenges will remain relevant to the Army and its ability to win the fight. The S&T community is committed to help enable the Army achieve its vision of an expeditionary, tailorable, scalable, self-sufficient, and leaner force, by addressing these challenges:

—Enabling greater force protection for Soldiers, air and ground platforms, and bases (e.g., lighter and stronger body armor, helmets, pelvic protection, enhanced vehicle survivability, integrated base protection).
—Easing overburdened Soldiers in small units (both cognitive and physical burden, e.g., lighter weight multi-functional materials).
—Enabling timely mission command and tactical intelligence to provide situation awareness and communications in ALL environments (mountainous, forested, desert, urban, jamming, etc.).
—Reducing logistic burden of storing, transporting, distributing and retrograding materials.
—Creating operational overmatch (enhancing lethality and accuracy).
—Achieving operational maneuverability in all environments and at high operational tempo (e.g., greater mobility, greater range, ability to operate in high/hot environments).
—Enabling early detection and treatment for Traumatic Brain Injury (TBI) and Post Traumatic Stress Disorder (PTSD).
—Improving operational energy (e.g., power management, micro-grids, increased fuel efficiency engines, higher efficiency generators, etc.).

[4] "Marching Orders," General Raymond T. Odierno, 38th Chief of Staff, U.S. Army, January 2012.

—Improving individual and team training (e.g., live-virtual-constructive training).
—Reducing lifecycle costs of future Army capabilities.

In addition to these enduring challenges, the S&T community conducts research and technology development that impacts our ability to maintain an agile and ever ready force. This includes efforts such as establishing environmentally compatible installations and materiel without compromising readiness or training, creating leader selection methodologies, and new test tools that can save resources and reduce test time, and establishing methods and measures to improve Soldier and unit readiness and resilience.

The Army S&T strategy acknowledges that we must respond to the new fiscal environment and changing technology playing field. Many critical technology breakthroughs are being driven principally by commercial and international concerns. We can no longer do business as if we dominate the technology landscape. We must find new ways of operating and partnering. We realize that we should invest where the Army must retain critical capabilities but reap the benefits of commercially driven technology development. No matter the source, we will ensure the Army is aware of the best and most capable technologies to enable a global, networked and full-spectrum joint force in the future. As the U.S. rebalances its focus by region and mission, it must continue to make important investments in emerging and proven capabilities. In a world where all have nearly equal access to open technology, innovation is the most important discriminator in assuring technology superiority.

The Chief of Staff of the Army has made his vision clear.

> "The All-Volunteer Army will remain the most highly trained and professional land force in the world. It is uniquely organized with the capability and capacity to provide expeditionary, decisive landpower to the Joint Force and ready to perform across the range of military operations to Prevent, Shape, and Win in support of Combatant Commanders to defend the Nation and its interests at home and abroad, both today and against emerging threats."[5]—*General Raymond T. Odierno, 38th Chief of Staff, Army*

The Army is relying on its S&T community to carry out this vision for the Army of the future.

Implementing New Processes

Turning science into capability takes a continuum of effort including fundamental research, the development and demonstration of technology, the validation of that technology and its ultimate conversion into capability. From an S&T materiel perspective, this includes the laboratory confirmation of theory, the demonstration of technical performance, and the experimentation with new technologies to identify potential future capabilities and to help refine/improve system designs. But the S&T Enterprise is also charged with helping to conceptualize the future—to use our understanding of the laws of physics and an ability to envision a future environment to broaden the perspective of the requirements developers as well as the technology providers.

As part of this continuum, the Army has adopted a 30 year planning perspective to help facilitate more informed program planning and budget decisions. A major part of the S&T strategy is to align S&T investments to support the acquisition Programs of Record (PoRs) throughout all phases of their lifecycle and across the full DOTMLPF (Doctrine, Organization, Training, Materiel, Leadership, Personnel, and Facilities) process. By expanding the perspective, we are able to identify areas where there are unaffordable alignments of activities (such as multiple major Engineering Change Proposals in the same portfolio within the same 2–3 year timeframe) or unrealistic alignments (such as planned technology upgrades to a system that has already transitioned into sustainment). With that information in mind, the Army has established "tradespace" to generate options that inform strategic decisions that allow the Army to stay within its fiscal top line while maximizing its capabilities for the Warfighter.

This new and ongoing process, known as the Long Range Investment Requirements Analysis (LIRA), has put additional rigor into the development of the Army's budget submission and creates an environment where the communities who invest in all phases of the materiel lifecycle work together to maximize the Army's capabilities over time. From an S&T perspective, it clearly starts to inform the materiel community as to WHEN technology is needed for insertion as part of a planned upgrade. It also cues us as to when to start investing for replacement platforms. In addition, this long-range planning can introduce opportunities for convergence of ca-

[5] Gen Raymond Odierno, 38th Chief of Staff Army, "CSA Strategic Priorities, Waypoint 2", 2014.

pabilities such as the development of a single radar that can perform multiple functions for multiple platforms or the convergence of cyber and Electronic Warfare (EW) capabilities into one system. Aside from the obvious benefits achieved by laying out the Army's programs and seeing where we may have generated unrealizable fiscal challenges, it has reinvigorated the relationships and strengthened the ties between the S&T community and their Program Executive Office (PEO) partners. We are working together to identify technical opportunities and the potential insertion of new capabilities across this 30 year timeframe.

The LIRA process was used to inform the development of the fiscal year 2015 President's Budget. As the Army faced a dramatic decline in its modernization accounts (a 40 percent decrement over the next 2 years), we used the results of the LIRA to ensure that we had a fiscally sound strategy.

The S&T Portfolio

The nature of S&T is such that continuity and stability have great importance. Starting and stopping programs prevents momentum in research and lengthens the timelines for discovery and innovation. While the Army S&T portfolio gains valuable insight from the threat community, this only represents one input to the portfolio and likely describes the most probable future. To have a balanced outlook across all the possible futures requires that the portfolio also address the "possible" and "unthinkable." The Army's S&T portfolio is postured to address these possible futures across the eight technology portfolios identified Figure 1.

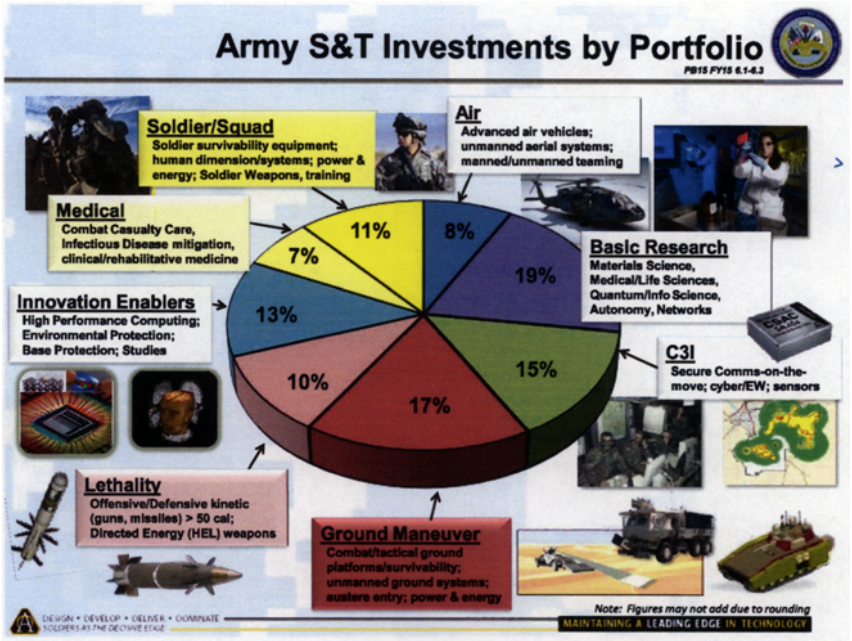

Figure 1. Army S&T Investments by Portfolio

The efforts of the S&T Enterprise are managed by portfolio to ensure maximum synergy of efforts and reduction of unnecessary duplication. The S&T program is organized into eight investment portfolios that address challenges across six Army-wide capability areas (Soldier/Squad; Air; Ground Maneuver; Command, Control, Communications, and Intelligence (C3I); Lethality; and Medical) and two S&T enabling areas (Basic Research and Innovation Enablers).

The 2014 Quadrennial Defense Review (QDR) protects and prioritizes key investments in technology to maintain or increase capability while forces grow leaner. This is an opportunity to look at innovative applications of technology. As a result, in the fiscal year 2015 President's budget request, the Army is maintaining, and shifting investments where necessary within portfolios as well at various stages of

technology maturity, emphasizing on technology areas that enable the Army to be leaner, expeditionary, and more lethal. In fiscal year 2015, our Advanced Technology Development investments increase to 42 percent of our $2.2 billion budget. This is a deliberate increase from previous years as the Army looks to its S&T community to conduct more technology demonstration/prototyping initiatives that will inform future Programs of Record (PoRs).

We are now in an era of declining acquisition budgets and are mindful of the challenges this brings to our S&T programs. We will have fewer opportunities for transition to Programs of Record in the next few years. This "pause" in acquisition does however afford us the opportunity to further develop and mature technologies, ensuring that when acquisition budgets do recover, S&T will be properly positioned to support the Army's next generation of capabilities. This year finds the Army beginning to rebalance its S&T funding between Basic Research, applied research and advanced technology development. We appreciate the flexibility that was provided to the DOD S&T executives to better align our funding to our Service/Agency needs after years of proscriptive direction.

The Army is maintaining its level of investment in the S&T portfolio from fiscal year 2014 to fiscal year 2015, dedicating more than $2.2 billion to meeting the Army's needs and priorities for future capability: $424 million in Basic Research, $863 million in Applied Research, and $918 million in Advanced Technology Demonstrations. Specifically you will see the Army shifting or increasing emphasis on research areas that support the next generation of combat vehicles (including power and energy efficiency, mobility and survivability systems), Anti-Access/Area Denial (A2/AD) technologies such as assured Position Navigation and Timing (PNT) and austere entry capabilities, Soldier selection tools and training technologies, as well as long range fires. Two of these efforts, the Future Infantry Fighting Vehicle (FIFV) and the assured Position Navigation and Timing (PNT) efforts are being done in collaboration with the respective PEOs to ensure that the capability developed and demonstrated not only helps to refine the requirements for the future PoRs but establishes an effective link for transition. We are also increasing our investments in vulnerability assessments of both technology and systems as well as expanding our Red Teaming efforts to identify potential vulnerabilities in emerging technologies, systems and systems-of-systems, including performance degradation in contested environments, interoperability, adaptability, and training/ease of use. This year begins the re-alignment necessary to implement our strategy of investing in areas critical to the Army—areas where we have critical skills sets, and leveraging others (sister services, other government agencies, academia, industry, allies) for everything else.

We anticipate a future where rapidly advancing technologies such as autonomous systems, high yield energetics, immersive training environments, alternative power and energy solutions, and the use of smart phones and social media will become critical to military effectiveness. The Army will continue to develop countermeasures to future threat capabilities and pursue technological opportunities. Enemies and adversaries however, will counter U.S. technological advantages through cover, concealment, camouflage, denial, deception, emulation, adaptation, or evasion. Finally, understanding how humans apply technology to gain capabilities and train will continue to be at least as important as the technologies themselves.

We are mindful however that the Army will continue to be called on for missions around the globe. The Army is currently deployed in 160 countries conducting missions that range from humanitarian support to stability operations to major theater warfare. As we have seen in the last few months, the world is an unpredictable place, and our Soldiers must have the capabilities to deal with an ever changing set of threats.

S&T Portfolio Highlights

I'd like to highlight a few of our new initiatives and remind you of some of our ongoing activities that will help frame the options for the Army of the future.

Soldier/Squad Portfolio (Fiscal Year 2015 = $252 Million)

One of the important initiatives currently underway that we anticipate will make major inroads into our efforts to lighten the Soldier's load is the development of a Soldier Systems Engineering Architecture, which has a $45 million investment in fiscal year 2015. This architecture, developed in concert with our acquisition and requirements community, is an analytical decision-based model through which changes in Soldier system inputs (loads, technology/equipment, physiological & cognitive state, stress levels, training, etc.) may be assessed to predict changes in performance outputs of the Soldier system in operationally relevant environments. By using a systems engineering approach, the model will result in a full system level

analysis capable of predicting impacts of both materiel and non-materiel solutions on fully equipped Soldiers performing operational missions/tasks

In keeping with the CSA's vision, our S&T efforts also support the Army's training modernization strategy by developing technologies for future training environments that sufficiently replicate the operational environment. We are also developing new training effectiveness measures and methods, ensuring that these new training technologies can rapidly and effectively transfer emerging warfighting experience and knowledge into robust capabilities. In addition, the need to reduce force structure has increased the importance of our research in the area of personnel selection and classification. This research will provide the Army with methods to acquire and retain candidates best suited for the Army—increasing our flexibility to adapt to changes in force size, structure and mission demands. Other important research includes developing scientifically valid measures and metrics to assess command climate and reduce conduct related incidences, including sexual harassment and assault in units to ensure the Army can maintain a climate of dignity, respect and inclusion.

Air Portfolio (Fiscal Year 2015 = $176 Million)

As the lead service for rotorcraft, owning and operating over 80 percent of the Department of Defense's vertical lift aircraft, the preponderance of rotorcraft technology research and development takes place within the Army. Our key initiative, the Joint Multi-Role Technology Demonstrator (JMR TD) program which has a $54 million investment in fiscal year 2015, is focused on addressing the Anti-Access/Area Denial (A2/AD) need for longer range and more efficient combat profiles. As we shift to the Pacific Rim focus, future Areas of Operation (AO) may be sixteen times larger than those of our current AOs. The Army needs a faster, more efficient rotorcraft, capable of operating in high/hot environments (6,000 feet and 95 degrees) with significantly decreased operating costs and maintenance required. The new rotorcraft will also require improved survivability against current and future threats. The goal of the JMR TD effort is to reduce risk for the Future Vertical Lift planned PoR, the Department of Defense's next potential "clean sheet" design rotorcraft. The overall JMR TD effort will use integrated government/industry platform design teams and exercise agile prototyping approaches. At the same time, the Army is collaborating with DARPA on their x-plane effort. While the DARPA program is addressing far riskier technologies that are not constrained by requirements, we will look to leverage technology advancements developed under the DARPA effort where possible.

Another initiative that we are beginning in fiscal year 2015, with an investment of $32 million, is addressing one of the biggest causes of aircraft loss—accidents that occur while operating in a Degraded Visual Environments (DVE). DVE is much more than operating while in brown out—this effort looks at mitigating all sources of visual impairment, either those caused by the aircraft itself (brownout, whiteout) or other "natural" sources (rain, fog, smoke, etc.). We are currently conducting a synchronized, collaborative effort with PEO Aviation to define control system, cueing, and pilotage sensor combinations which enable maximum operational mitigation of DVE. This S&T effort will result in a prioritized list of compatible, affordable DVE mitigation technologies, and operational specification development that will help inform future Army decisions. This program is tightly coupled with the PEO Aviation strategy and potential technology off-ramps will be transitioned to the acquisition community along the way, when feasible.

Ground Maneuver Portfolio (Fiscal Year 2015 = $383 Million)

The Ground Maneuver Portfolio is focused on maturing and demonstrating technologies to enable future combat vehicles, including the FIFV. The fiscal year 2015 S&T investment in FIFV is $131 million. In fiscal year 2015, you will see the beginning of a focused initiative done in collaboration with PEO Ground Combat Systems, to develop critical sub-system prototypes to inform the development and requirements for the Army's FIFV. These sub-system demonstrators focus on mobility (e.g., engine, transmission, suspension); survivability (e.g., ballistic protection, under-body blast mitigation, advanced materials); Active Protection Systems (APS); a medium caliber gun and turret; and an open vehicle power and data architecture that will provide industry with a standard interface for integrating communications and sensor components into ground vehicles.

Armor remains an Army-unique challenge and we have persistent investments for combat and tactical vehicle armor, focusing not only on protection but also affordability and weight reduction. We continue to invest in advanced materials and armor technologies to inform the next generation of combat and tactical vehicles.

In fiscal year 2015, this portfolio continues to shift its focus to address A2/AD challenges. We've increased efforts on technologies to enable stand-off evaluation of austere ports of entry and infrastructure to better enable our ability to enter areas of conflict. We are also maintaining technology investments in detection and neutralization of mines and improvised explosive devices to ensure freedom of maneuver.

C3I Portfolio (Fiscal Year 2015 = $321 Million)

The C3I portfolio provides enabling capability across many of the Army enduring challenges, but specifically seeks to provide responsive capabilities for the future in congested Electro-Magnetic environments. These capabilities are supported by sustained efforts in sensors, communications, electronic warfare and information adaptable in dynamic, congested and austere (disconnected, intermittent and limited) environments to support battlefield operations and non-kinetic warfare. Renewed efforts in the C3I portfolio include reinvigorating efforts in sensor protection. We continue to invest in EW vulnerability analysis to perform characterization and analysis of radio frequency devices to develop detection and characterization techniques, tactics, and technologies to mitigate the effects of contested environments (such as jamming) on Army C4ISR systems.

Given the potential challenges that we face while operating in a more contested environment, we are placing additional emphasis on assured PNT, developing technologies that allow navigation in Global Positioning System (GPS) denied/degraded environments for mounted and dismounted Soldiers and unmanned vehicles such as exploiting signals of opportunity. The fiscal year 2015 investment in PNT is $24 million. We will study improvements for high sensitivity GPS receivers that could allow acquisition and tracking in challenging locations such as under triple canopy jungles, in urban areas, and inside buildings. We are developing Anti-Jam capabilities as well as supporting mission command with interference source detection and location and signal strength measurement, thereby enabling the Army to conduct its mission in challenging electromagnetic environments.

The C3I Portfolio also includes efforts in cyber, both defensive and offensive at an investment level of $44.5 million. Defensive efforts in cyber security will investigate and develop software, algorithms and devices to protect wireless tactical networks against computer network attacks. We are developing sophisticated software assurance algorithms to differentiate between stealthy life cycle attacks and software coding errors, as well as investigating and assessing secure coding methodologies that can detect and self-correct against malicious code insertion. We will research and design sophisticated, optimized cyber maneuver capabilities that incorporate the use of reasoning, intuition, and perception while determining the optimal scenario on when to maneuver, as well as the ability to map and manage the network to determine probable attack paths and the likelihood of exploitation.

On the offensive side of cyber operations, we will develop integrated electronic attack (EA) and computer network operations hardware and software to execute force protection, EA, electronic surveillance and signals intelligence missions in a dynamic, distributed and coordinated fashion.

We will demonstrate protocol exploitation software and techniques that allow users to remotely coordinate, plan, control and manage tactical EW and cyber assets; develop techniques to exploit protocols of threat devices not conventionally viewed as cyber to expand total situational awareness by providing access to and control of adversary electronic devices in an area of operations.

Lethality Portfolio (Fiscal Year 2015 = $230 Million)

In fiscal year 2015, you will see continued emphasis on the development of A2/AD capabilities through Long Range Fires and Counter Unmanned Aircraft technologies. S&T is focusing on advanced seeker technologies to enable acquisition of low signature threats at extended ranges, along with dual pulse solid rocket motor propulsion to provide longer range rockets and extend the protected areas of air defense systems. To support these capabilities, we are conducting research in new energetic materials focused on both propulsive and explosive applications. These materials have significantly higher energetic yield than current materials and will increase the both effectiveness of our systems and reduce their size.

We also continue to develop Solid State High Energy Lasers, at an investment level of $44.9 million in fiscal year 2015, to provide low cost defeat of rockets, artillery, mortars and unmanned aircraft. We have had multiple successes in High Energy Lasers, as we demonstrated successful tracking and defeat of mortars and unmanned aircraft in flight this year (fiscal year 2014) from our mobile demonstrator.

Additionally, we are supporting the Ground Maneuver Portfolio in the demonstration of a medium caliber weapon system, at an investment level of $13.5 million in

fiscal year 2015, to enable FIFV requirements for range and lethality including an airburst munition.

Medical (Fiscal Year 2015 = $143 Million)

The Medical portfolio addresses the wellness and fitness of our Soldiers from accession through training, deployment, treatment of injuries and return to duty or to civilian life. Ongoing efforts address multiple threats to our Soldiers' health and readiness. Medical research focuses on areas of physiological and psychological health that directly support the Chief of Staff of the Army Ready and Resilience Campaign and the Army Surgeon General's Performance Triad (Activity, Nutrition and Sleep). Research in these portfolios includes important areas such as Traumatic Brain Injury (TBI) and Post Traumatic Stress Disorder (PTSD), totaling $41.5 million in fiscal year 2015. In fiscal year 2015, $47 million has gone into continued research to mitigate infectious diseases prevalent in the Far East as well as combat casualty care solutions at the point of injury that will extend Soldier's lives during the extended distances associated with conducting operations in the Pacific.

TBI research efforts include furthering our understanding of cell death signals and neuroprotection mechanisms, as well as identifying critical thresholds for secondary injury comprising TBI. The Army is also evaluating other nontraditional therapies for TBI, and identifying "combination" therapeutics that substantially mitigate or reduce TBI-induced brain damage. Current Army funded research efforts in the area of PTSD are primarily focused upon development of pharmacologic solutions for the prevention and treatment of PTSD. A large-scale clinical trial is currently underway evaluating the effectiveness of Sertraline, one of two Selected Serotonin Reuptake Inhibitors (SSRIs) approved for the treatment of civilian PTSD, but not combat-related PTSD. This study will evaluate Sertraline's effectiveness in the treatment of combat-related PTSD both alone and in combination with psychotherapy.

Innovation Enablers (Fiscal Year 2015 = $275 Million)

As the largest land-owner/user within the DOD, it is incumbent upon the Army to be good stewards in their protection of the environment. As such, the Army develops and validates lifecycle models for sustainable facilities, creates dynamic resource planning/management tools for contingency basing, develops decision tools for infrastructure protection and resiliency and assesses the impact of sustainable materials/systems on the environment.

In addition, we conduct blast noise assessment and develop mitigation technologies to ensure that we remain "good neighbors" within Army communities and work to protect endangered species while we ensure that the Army mission can continue.

The High Performance Computing (HPC) Modernization Program, at an investment level of $181.6 million in fiscal year 2015, supports the requirements of the DOD's scientists and engineers by providing them with access to supercomputing resource centers, the Defense Research and Engineering Network (DREN) (a research network which matures and demonstrates state of the art computer network technologies), and support for software applications, including the experts that help to improve and optimize the performance of critical common DOD applications programs to run efficiently on advanced HPC systems maturing and demonstrating leading-edge computational technology.

The Army's Technology Maturation Initiatives effort, established in fiscal year 2012 enables a strategic partnership between the S&T and acquisition communities. This effort, funded at $75 million in fiscal year 2015, has become especially important as the Army heads into a funding downturn. We plan to use these funds to prepare the Army to capitalize on S&T investments as we come out of the funding "bathtub" near the end of the decade. We are using these Budget Activity 4 resources to target areas where acquisition programs intended to provide necessary capabilities have been delayed, such as assured PNT, the FIFV, and APS. We are investing resources that will either provide capability or inform/refine requirements for the Army's future systems (all of which will be done via collaborative programs executed with our acquisition/PEO partners).

This portfolio includes our ManTech efforts as well, funded at $76 million in fiscal year 2015. Last month, President Obama announced the launch of the Digital Manufacturing and Design Innovation Institute (DMDI). Headquartered in Chicago, Illinois, and managed by the U.S. Army's Aviation and Missile Research Development and Engineering Center, the DMDI Institute spearheads a consortium of 73 companies, universities, nonprofits, and research labs. The president announced a government investment of $70 million and matching private investments totaling $250 million for the institute. DMDI is part of the president's National Network of Manufac-

turing Innovation (NNMI) and will focus on the development of novel model-based design methodologies, virtual manufacturing tools, and sensor and robotics based manufacturing networks that will accelerate the innovation in digital manufacturing and increase U.S. competitiveness.

Basic Research (Fiscal Year 2015 = $424 Million)

Underpinning all of our efforts and impacting all of the enduring Army challenges is a strong basic research program. Army Basic Research includes all scientific study and experimentation directed toward increasing fundamental knowledge and understanding in those fields of the physical, engineering, environmental, and life sciences related to long-term national security needs. The vision for Army Basic Research is to advance the frontiers of fundamental science and technology and drive long-term, game-changing capabilities for the Army through a multi-disciplinary portfolio teaming our in-house researchers with the global academic community to ensure overwhelming land-warfighting capabilities against any future adversary.

While we have made some significant adjustments within the Basic Research investments within the Army, we will continue to emphasize several areas that we feel have a high payoff potential for the Warfighter. These areas include: Materials in Extreme Environments; Quantum Information and Sensing; Intelligent Autonomous Systems; and Human Sciences/Cybernetics.

For centuries, the fabrication of solid materials has hinged largely on manipulating a narrow range of temperatures and pressures. Our Materials in Extreme Environments initiative invests in new revolutionary and targeted scientific opportunities to discover and exploit the fundamental interaction of matter under extreme static pressures and magnetic fields, controlled electromagnetic wave interactions (microwave, electrical) and acoustic waves (ultrasound) to dramatically enhance fabrication and create engineered materials with tailored microstructures and revolutionary functionalities. Additionally, we are in the midst of a second quantum revolution—moving from merely computing quantum properties of systems to exploiting them.

To enable the Warfighter, animal-like intelligence is desired for simple autonomous platforms, such as robotic followers, and for aerial and ground sensor platforms. We are investing in research that will enable highly intelligent systems that allow platforms to set waypoints autonomously, increasing mission effectiveness; followers that recognize the actions of their unit, that can perceive when the unit is deviating from a previously prescribed plan and know enough to query why; and that recognize when the unit is resting and be capable of doing so without explicit instructions from the Soldier.

Regardless of specific definition, human sciences are critical and can safely be predicted to become pervasive across all Army research activities. Cognitive predictions of social person-to-person communication based on observed gestures, eye movement, and body language are becoming possible. In addition, brain-to-brain interaction is emerging as a potential paradigm based on external sensors and brain stimulation. The Army will continue to study these and other possible techniques, to understand shared knowledge, social coordination, discourse comprehension, and detection and mitigation of conflict. Cognitive models combined with sensors also have the potential for dramatic breakthroughs in human-autonomy interaction, including aspects such as active learning algorithms, real-time crowd-sourcing with humans and machines in the cloud, and maximizing artificial intelligence (AI) prediction accuracy. Devices and sensors that are wearable or implantable (including biomarkers and drug therapy) have the potential to enhance performance dramatically and to augment sensory information through new human-sensor-machine interface designs.

The role of Basic Research is to provide the knowledge, technology, and advanced concepts to enable the best equipped, trained and protected Army to successfully execute the national security strategy, cannot be understated. The key to success in Basic Research is picking the right research challenges, the right people to do the work, and providing the right level of resources to maximize the likelihood of success.

Impact of Sequestration

I am often asked what impact sequestration had on the Army's S&T portfolio, so I would like to address some of the impacts we have seen. The fiscal year 2013 application of sequestration targets (hitting every Program Element in the S&T portfolio by a set percentage) forced the Army into a scenario where we decremented programs that we would have protected, if given the opportunity. This lack of flexibility made for some very bad business and technical ramifications. Within the S&T

community, we were able to balance our sequestration targets at the Program Element, vice Project level—giving us the ability to avoid civilian

Reduction in Force (RIF) actions where possible. That said, sequestration did result in unfunded efforts and delays in applied research and technology development areas across the S&T portfolio. More generally, the sequestration cuts added unnecessary risk to acquisition programs and delayed the transition of critical capabilities to the Warfighter.

However, by far the most serious consequence of sequestration (and the related pay freezes, shutdowns, conference restrictions, etc.) has been the impact on our personnel. Without a world-class cadre of scientists and engineers, the Army S&T enterprise would be unable to support the needs of the Army. The Army Labs and Research, Development and Engineering Centers have reported multiple personnel leaving for other job opportunities or early retirement. For example, the Night Vision and Electronic Sensors Directorate lost eight personnel in the 2 months prior to the well-publicized DOD-wide furloughs, compared to an average annual loss of around 19 personnel. These losses include personnel across experience levels with specialized expertise critical to the Army. While the average attrition rate over the past 2 years is running at about 8 percent (similar to a typical attrition rate found in prior years), the concerning impact is that 60 percent of the personnel leaving the Army are NOT eligible for retirement. This is a big change. During our exit interviews, reasons cited included conference restrictions (impeding the ability to progress professionally) coupled with increasing job insecurity due to budget decrements and planned manpower reductions. Complicating this loss of technical expertise is the restriction on hiring replacements for the lost government civilians. We are on a replacement cycle that varies between 1 hire per every 3 losses at one lab, to 1 hire for every 20 losses at another. This pattern of loss is unsustainable if we hope to maintain a premier technical workforce. Finally, as we address the 2013 National Defense Authorization Act (NDAA), Section 955 language which mandates a reduction in the civilian workforce commensurate with a reduction in the military, we must confront the impacts of any civilian reductions, which are implemented through a personnel process that tends to primarily impact those employees who have less tenure in the government. For the S&T community that typically impacts those areas of new technical emphasis within the DOD—key areas such as cyber research and systems biology.

While the Bipartisan Budget Act has provided some relief and stability for fiscal year 2014 and fiscal year 2015, the uncertainty again looming on the horizon makes it even more difficult to recruit and retain the scientists and engineers the Army depends on. As you know, the key to any success within the Army lies with our people.

The S&T Enterprise Infrastructure and Workforce

Our laboratory infrastructure is aging, with an average approximate facility age of 50 years. Despite this, the S&T Enterprise manages to maximize the scarce sustainment, restoration, and modernization funding and the authorities for minor military construction using NDAA, Sec. 219 funding to minimize the impact on the R&D functions with the Enterprise. However, we are only making improvements to our infrastructure at the margins, and where possible we have used MILCON, through your generous support and unspecified minor construction to modernize facilities and infrastructure. However, we do acknowledge that much of the Army is in a similar position. This is not a long-term solution. While the authorities that you have given us have been helpful, they alone are not enough, and we are still faced with the difficulty of competing within the Army for ever-scarcer military construction dollars at the levels needed to properly maintain world-class research facilities. This will be one of our major challenges in the years to come and I look forward to working with OSD and Congress to find a solution to this issue.

The S&T community affords us the flexibility and agility to respond to the many challenges that the Army will face. Without the world-class cadre of over 12,000 Federal civilian scientists and engineers and the infrastructure that supports their work, the Army S&T Enterprise would be unable to support the needs of the Warfighter. To maintain technological superiority now and in the future, the Army must maintain an agile workforce. Despite this current environment of unease within the government civilian workforce, exacerbated by conference restrictions, budget uncertainty, furloughs, and near zero pay increases, we continue to have an exceptional workforce. But, as I mentioned earlier, attracting and retaining the best science and engineering talent into the Army Laboratories and Centers is becoming more and more challenging. Our laboratory personnel demonstrations give us the flexibility to enhance recruiting and afford the opportunity to reshape our workforce, and I appreciate Congress' continued support for these authorities to include the

flexibilities given to the Laboratories and Centers in the 2014 NDAA, Section 1107 language. The flexibilities given to the laboratories and centers allow the laboratory directors the maximum management flexibility to shape their workforce and remain competitive with the private sector.

The Army S&T Enterprise cannot survive without developing the next generation of scientists and engineers. We continue to have an amazing group of young scientists and engineers that serve as role models for the next generation. For example, last year Dr. Ronald Polcawich, a researcher at the U.S. Army Research Laboratory (ARL), was named by President Obama to receive a 2012 Presidential Early Career Award for Scientists and Engineers as one of the Nation's outstanding young scientists for his work in Piezoelectric-Micro Electro-Mechanical Systems (PiezoMEMS) Technology. Dr. Polcawich, is leading a team of researchers at the ARL in studying PiezoMEMS with a focus on developing solutions for RF systems and actuators for millimeter-scale robotics. These actuators combined/integrated with low power sensors are being developed to enable millimeter-scale mechanical insect-inspired robotic platforms.

The need for science, technology, engineering, and mathematics (STEM) literacy, the ability to understand and apply concepts from science, technology, engineering and mathematics in order to solve complex problems, goes well beyond the traditional STEM occupations of scientist, engineer or mathematician. The Army also has a growing need for highly qualified, STEM-literate technicians and skilled workers in advanced manufacturing, logistics, management and other technology-driven fields. Success and sustainment for the Army S&T Enterprise depends on a STEM-literate population to support innovation and the Army must contribute to building future generations of STEM-literate and agile talent.

Through the Army Educational Outreach Program (AEOP), funded at $9 million in fiscal year 2015, the Army makes a unique and valuable contribution to meet the national STEM challenge—a challenge which includes the growing demand for STEM competencies; the global competitiveness for STEM talent; an unbalanced representation of our Nation's demographics in STEM fields; and the critical need for an agile and resilient STEM workforce. AEOP offers a cohesive, collaborative portfolio of STEM programs that provides students, as well as teachers, access to our world-class Army technical professionals and research centers. Exposure to STEM fields and STEM professionals is critical to growing the next generation of STEM-literate young men and women who will form the Army's workforce of tomorrow.

In the 2012–2013 academic year, AEOP directly engaged more than 66,000 students and nearly 1,500 teachers in authentic research experiences. Almost 2,351 Army Scientists and Engineers (S&E's) provided mentorship, either from our in-house research laboratories or through our university partnerships. Additionally in fiscal year 2013, we initiated a comprehensive evaluation strategy (the first of its kind) that uses the government and a consortium of STEM organizations known for their nationwide education and outreach efforts to annually assess our program. Aligned with Federal guidance, AEOP requires the evaluation of all elements of the program based on specific, cohesive, metrics and evidence-based approaches to achieve key objectives of Army outreach; increased program efficiency and coherence; the ability to share and leverage best practices; as well as focus on Army priorities. The AEOP priorities are:

—STEM Literate Citizenry: Broaden, deepen and diversify the pool of STEM talent in support of the Army and our defense industry base.

—STEM Savvy Educators: Support and empower educators with unique Army research and technology resources.

—Sustainable Infrastructure: Develop and implement a cohesive, coordinated and sustainable STEM education outreach infrastructure across the Army.

For fiscal year 2015, we are concentrating on implementing evidence-based program improvements, strengthening additional joint service sponsored efforts, and identifying ways to expand the reach and influence of successful existing programs by leveraging partnerships and resources with other agencies, industry and academia.

New Approaches to Enhance Innovation

It is widely acknowledged that innovation depends on bringing multiple scientific disciplines together to engage in collaborative projects—often yielding unpredictable, yet highly productive results. Formal and informal interactions among scientists lead to knowledge-building and research breakthroughs. These types of collaborations are happening on a day-to-day basis across our labs and engineering centers to produce the superior technology that our Army needs today, tomorrow and beyond. With shrinking budgets and huge leaps in the pace of technological change,

our Army S&T organizations must do more with less and faster than ever before to develop technology that will ensure mission success for the Army's first battle after next. To this end, we must more succinctly leverage scientific discovery from our academic and industry base by increasing the scientific engagement and flow of ideas that leads to ground breaking innovation.

In 1945, Vannevar Bush's concepts documented in "Science—the Endless Frontier" stressed the necessity of a robust/synergistic university, industry and government laboratory research system. Over the years, the rigid and insular nature of the defense laboratories have caused an erosion of that university/industry/government lab synergy that is critical to the discovery, innovation and transition of science and technology important to national security.

In an effort to reenergize that synergy, the U.S. Army Research Laboratory (ARL) is working to extend their alliances through an Open Campus Concept that brings together under one roof the triad of industry, academia, and government. Leveraging the cutting-edge innovation of academia, the system development and transition expertise of industry and their own Army-focused fundamental research; ARL can harness the power of the triad to produce revolutionary science and technology more efficiently and effectively. The Open Campus Concept creates an ecosystem for academia, defense labs, and industry to share people, facilities and resources to develop and deliver transformative science oriented on solving complex Army problems. It will provide the means for our world-class scientific talent to work together in state-of-the-art facilities to provide innovation that allows rapid transition of technology to our Soldiers. ARL's Open Campus Concept could lead to a new business model that would transform the defense laboratory enterprise into an agile, efficient and effective laboratory system that supports the continuous flow of people and ideas to ensure transformative scientific discovery, innovation and transition critical to national security.

Finally, we are increasingly mindful of the globalization of S&T capabilities and expertise. Our International S&T strategy provides a framework to leverage cutting edge foreign science and technology enabled capabilities and engages with allies through Global S&T Watch. Global S&T Watch is a systematic process for identifying, assessing, and documenting relevant foreign research and technology developments. The Research, Development and Engineering Command's (RDECOM) International Technology Centers (ITCs), Engineer Research and Development Center (ERDC) international research office and the Medical Research Materiel Command's OCONUS laboratories identify and document relevant foreign S&T developments. We have initiated a new process to strategically identify and selectively engage our allies when their technologies and materiel developments can contribute to Army needs and facilitate coalition interoperability. The resultant engagements will augment the existing bilateral leadership forums we currently maintain with the United Kingdom, Canada, Germany, and Israel which provide both visibility of and management decisions on allied developments that merit follow-up for possible collaboration.

Summary

As the Army S&T program continues to identify and harvest technologies suitable for transition to our force, we aim to remain ever vigilant of potential and emerging threats. We are implementing a strategic approach to modernization that includes an awareness of existing and potential gaps; an understanding of emerging threats; knowledge of state-of-the-art commercial, academic, and government research; as well as a clear understanding of competing needs for limited resources. Army S&T will sharpen its research efforts to focus upon those core capabilities it needs to sustain while identifying promising or disruptive technologies able to change the existing paradigms of understanding. Ultimately, the focus remains upon Soldiers; Army S&T consistently seeks new avenues to increase the Soldier's capability and ensure their technological superiority today, tomorrow, and decades from now. The Army S&T mission is not complete until the right technologies provide superior, yet affordable, overmatch capability for our Soldiers. I will leave you with a last thought from the Secretary of the Army, the Honorable John McHugh.

> "Our Strategic Vision is based on a decisive technological superiority to any potential adversary."[6] *—Honorable John W. McHugh, 21st Secretary of the Army*

This is an interesting, yet challenging, time to be in the Army. Despite this, we remain an Army that is looking towards the future while taking care of the Soldiers today. I hope that we can continue to count on your support as we move forward,

[6] Terms of Reference, fiscal year 2012 Army Science Board Summer Study, Secretary of the Army, John M. McHugh, October 28, 2011.

and I would like to again thank the members of the Committee for all you do for our Soldiers.

Senator DURBIN. Thank you, Ms. Miller.

Dr. Walker.

STATEMENT OF DR. DAVID WALKER, DEPUTY ASSISTANT SECRETARY OF THE AIR FORCE FOR SCIENCE, TECHNOLOGY, AND ENGINEERING

Dr. WALKER. Thank you, Mr. Chairman. Chairman Durbin, Senator Cochran, members of the subcommittee, I am pleased to have an opportunity today to provide testimony on the Air Force science and technology program.

The globalization and the proliferation of technology means that we have a wide spectrum of threats that we have to face, which has led to competition across all domains that we operate in. As our Chief of Staff stated in his recent vision, "Despite the best analysis and projection by national security experts, the time and place of the next crisis are never certain and rarely what we expect."

To guarantee our security in this dynamic environment requires that we learn lessons from the past couple of decades of war that we have been involved in but also be able to creatively visualize what our future will be and to develop a science and technology program to address that.

In this space, we are really finding great opportunity. The Air Force scientists and engineers continue to evolve and advance innovative, game-changing technologies and enabling technologies that will transform the landscape of how the Air Force flies, flights, and wins in the airspace and cyberspace.

In close coordination with the requirements, intelligence, and acquisition communities, we have structured our S&T program to address our highest priority needs of the Air Force, to execute a balanced and integrated program that is responsive to the Air Force core mission, and to advance critical technical competencies needed to address future research.

The Air Force as a whole had to make difficult trades between force structure, readiness, and modernization in this year's President's budget submission. The Air Force S&T request is approximately $2.3 billion, which is about a 6.2-percent decrease over the fiscal year 2014 request. However, when you look at this compared to the overall Air Force RDT&E (research, development, testing, and evaluation) input in the fiscal year 2015, that was a decrease of 9 percent. So S&T actually fared well versus the RDT&E as a whole.

Our budget request has rebalanced our basic research spending as part of our overall portfolio to increase our emphasis on technology demonstrations. It also emphasized our game-changing technologies of hypersonics, autonomy, directed energy, and fuel-efficient propulsion technologies. All of these provide us a greater range, speed, and lethality for operations in highly contested environments described in our 2014 QDR (Quadrennial Defense Review) report.

As I stated earlier, our scientific opportunities lie between learning from the past and visualizing the future. The increased laboratory hiring and personnel management authorities and the flexi-

bilities provided by Congress over the last several years have done much to improve our ability to attract the Nation's best talents and to explore these opportunities. However, we still have work to do to ensure that we sustain the quality of our laboratories and if we have long-term budget decreases, this will impact our ability to fund this. So funding uncertainties and the decreases in budget really lead to an uncertain future for our S&T, which leads to loss of opportunities for new discovery and for innovative technologies.

As a result of sequestration in fiscal year 2013, we canceled or delayed or rescoped over 100 contracts, resulting in a cost and an extended technology development schedule, ultimately delaying improved capabilities for the warfighter. For example, the rescoping of work on a very sophisticated ground-based imaging of objects in extremely high altitude orbits is going to delay technology availability for at least a year for a transition into our Air Force Space Command.

PREPARED STATEMENT

In closing, I firmly believe maintaining and even expanding our technological advantage is vital to ensuring assured access and freedom of action in the airspace and cyberspace. The focused and balanced investments of the Air Force fiscal year 2015 S&T program are hedges against an unpredictable future and provide a pathway to a flexible, precise, and lethal force at a relatively low cost in relation to the return on investment.

On behalf of the dedicated scientists and engineers of the Air Force S&T enterprise, I thank you again for the opportunity to testify today and look forward to your questions and thank you all for your support of the Air Force S&T community.

[The statement follows:]

PREPARED STATEMENT OF DR. DAVID E. WALKER

INTRODUCTION

Chairman Durbin, Vice Chairman Cochran, and Members of the Subcommittee, I am pleased to have the opportunity to provide testimony on the fiscal year 2015 Air Force Science and Technology (S&T) Program, especially during this unprecedented time in our history.

Our Nation is one of a vast array of actors in a complex, volatile, and unpredictable security environment. Globalization and the proliferation of technology mean we face threats across a wide spectrum and competition across all domains. We're confronted by ever-evolving adversaries ranging from one person with a single interconnected computer to sophisticated capable militaries and everything in between. We're also challenged by the shear pace of change among our adversaries fueled by profound information and technology diffusion worldwide. As stated by the Chief of Staff of the Air Force in the Global Vigilance, Global Reach and Global Power For Our Nation vision, "despite the best analyses and projections by national security experts, the time and place of the next crisis are never certain and are rarely what we expect." Success and the guaranty of security in this dynamic environment require that we both take lessons learned from the last decade of conflict and creatively visualize the future strategic landscape. It's in this space, between learning from the past and keeping an open eye to the future, where we find opportunity.

The focused and balanced investments of the Air Force fiscal year 2015 S&T Program are hedges against the unpredictable future and provide pathways to a flexible, precise and lethal force at a relatively low cost in in relation to the return on investment. The Undersecretary of Defense for Acquisition, Technology and Logistics recently reminded us that complacency now and in the future is simply not an option. Maintaining, and even expanding, our technological advantage is vital to ensuring sustained freedom of access and action in air, space and cyberspace.

AIR FORCE FISCAL YEAR 2015 S&T PROGRAM

The Air Force as a whole had to make difficult trades between force structure (capacity), readiness, and modernization (capability) in the Service's fiscal year 2015 President's Budget submission to recover from budget uncertainty over the two previous fiscal years. The Air Force fiscal year 2015 President's Budget request for S&T is approximately $2.1 billion, which includes nearly $178 million in support of devolved programs consisting of High Energy Laser efforts and the University Research Initiative. This year's Air Force S&T budget request represents a decrease of $141 million or a 6.2 percent decrease from the fiscal year 2014 President's Budget request, a slightly larger reduction as compared to the overall Air Force topline reduction. This budget request rebalances basic research spending as part of the overall portfolio to increase emphasis on conducting technology demonstrations. The Air Force was able to reduce funding in the aerospace systems and materials areas while still advancing capabilities for the Air Force and the Department of Defense (DOD) by smartly leveraging research being conducted by the Defense Advanced Research Projects Agency (DARPA) in the hypersonics area.

We've learned a great deal over the last decade. The dedicated scientists and engineers of the Air Force Research Laboratory (AFRL) have successfully supported warfighters during conflicts in Iraq, Afghanistan, and North Africa through the rapid development of systems and capabilities including persistent intelligence, surveillance, and reconnaissance (ISR); data fusion and integration from multiple sensors; and near real-time monitoring of some orbiting U.S. and commercial spacecraft assets. With the pivot to the Pacific as outlined in the Defense Strategic Guidance, we must continue to evolve and advance "game-changing" and enabling technologies which can transform the landscape of how the Air Force flies, fights and wins against the high-end threats in contested environments envisioned in the future.

In close coordination with the requirements, intelligence and acquisition communities, we have structured our Air Force fiscal year 2015 S&T Program to address the highest priority needs of the Air Force across the near-, mid- and far-term; execute a balanced and integrated program that is responsive to Air Force core missions; and advance critical technical competencies needed to address the full range of product and support capabilities. The Air Force continues to focus efforts to deliberately align S&T planning, technology transition planning, development planning and early systems engineering. The linkages between these planning activities are critical to initiating acquisition programs with more mature technologies and credible cost estimates, and we are institutionalizing these linkages in Air Force policy. Air Force S&T provides critical inputs at several phases of the Chief of Staff of the Air Force's Air Force 2023 strategic planning effort including helping to shape the "realm of the possible" when envisioning long term strategy, offering technologies to expand the strategic viewpoint and identifying potential solutions to requirements and capability gaps. Our forthcoming updated Air Force S&T strategy focuses on investing in S&T for the future, as well as leverages our organic capacity, and the capacity of our partners (domestic and international), to integrate existing capabilities and mature technologies into innovative, affordable, and sustainable solutions. This flexible strategy provides us the technological agility to adapt our S&T Program to dynamic strategic, budgetary, and technology environments and will shape prioritized actionable S&T plans.

NEAR TERM TECHNOLOGY TRANSITION

The Air Force continues to move our Flagship Capability Concept (FCC) projects toward transition to the warfighter. A well-defined scope and specific objectives desired by a Major Command (MAJCOM) are key factors in commissioning this type of an Air Force-level technology demonstration effort. The technologies are matured by the Air Force Research Laboratory with the intent to transition to the acquisition community for eventual deployment to an end user. These FCCs are sponsored by the using MAJCOM and are vetted through the S&T Governance Structure and Air Force Requirements Oversight Council to ensure they align with Air Force strategic priorities. In fiscal year 2014, the Air Force successfully completed and transitioned the Selective Cyber Operations Technology Integration (SCOTI) FCC and will continue work on the High Velocity Penetrating Weapon (HVPW) and Precision Airdrop (PAD) FCCs.

AFRL delivered the SCOTI FCC to the Air Force Life Cycle Management Center (AFLCMC) in September 2013, on time, on budget and within specification. SCOTI consists of cyber technologies capable of affecting multiple nodes for the purposes of achieving a military objective and gaining cyberspace superiority. SCOTI's robust, modular architecture provides vital extensibility to allow cyber warriors to keep pace with rapidly evolving threats. AFLCMC is evaluating the delivered SCOTI ar-

chitecture for integration with operational cyber mission software to directly meet the needs of a major capability area in the Air Force Cyberspace Superiority Core Function Master Plan. By successfully meeting the requirements of the stakeholder-approved Technology Transition Plan, SCOTI is the first FCC to transition and will serve as a baseline for current and future integrated cyber tools to provide needed effects for the warfighter.

The HVPW FCC was established to demonstrate critical technologies to reduce the technical risk for a new generation of penetrating weapons to defeat difficult, hard targets. This FCC matures technologies that can be applied to the hard target munitions acquisition including guidance and control, terminal seeker, fuze, energetic materials and warhead case design. This effort develops improved penetration capability of hard, deep targets containing high strength concrete with up to 2,500 feet per second (boosted velocity) impact in a GPS-degraded environment. This technology will demonstrate penetration capability of a 5,000 pound-class gravity weapon with a 2,000 pound weapon thus enabling increased loadout for bombers and fighters. Tests will demonstrate complete warhead functionality, and are scheduled to be completed the end of September 2014.

The PAD FCC was commissioned in response to a request from the Commander of Air Mobility Command for technologies to improve airdrop accuracy and effectiveness while minimizing risk to our aircrews. To date, PAD FCC efforts have focused on: early systems engineering analysis to determine major error sources, data collection, flying with crews, wind profiling, bundle tracking, and designing modeling and simulation activities. The Air Force Research Laboratory completed the bundle tracker development in fiscal year 2013 and in fiscal year 2014 began wind profile sensor development.

GAME-CHANGING TECHNOLOGIES

The Air Force S&T Program provides technology options to enable operations in anti-access, area-denial environments and transform the way we fly, fight and win in air, space and cyberspace. To illustrate how, I will highlight some of our efforts in game-changing and enabling technology areas:

Hypersonics

Speed provides options for engagement of time sensitive targets in anti-access/area-denial environments, and improves the survivability of Air Force systems. Hypersonic speed weapons are also a force multiplier as fewer are required to defeat difficult targets and fewer platforms are required from greater standoff distances. The Air Force S&T community continues to execute the high speed technology roadmaps developed with industry over the last 3 years. We are also building on the success of the X–51A Waverider scramjet engine hypersonic demonstrator, which on 1 May 2013 reached an approximate Mach Number of 5.1 during its fourth and final flight. The Air Force has focused multi-faceted, phased investments in game-changing technology for survivable, time-critical strike in the near term and a penetrating regional intelligence, surveillance, and reconnaissance (ISR) and strike aircraft in the far term.

The near term strike effort is the High Speed Strike Weapon (HSSW) program. This effort will mature cruise missile technology to address many of those items necessary to realize a missile in the hypersonic speed regime including: modeling and simulation; ramjet/scramjet propulsion; high temperature materials; guidance, navigation, and control; seekers and their required apertures; warhead and subsystems; thermal protection and management; manufacturing technology; and compact energetic booster technologies.

The Air Force conducts research and development in all aspects of hypersonic technologies in partnership with NASA, DARPA, and industry/academic sectors. The HSSW program will include two parallel integrated technology demonstration efforts to leverage DARPA's recent experience in hypersonic technologies that are relevant to reduce risk in key areas. One of the demonstrations will be a tactically-relevant demonstration of an air breathing missile technology that is compatible with Air Force 5th generation platforms including geometric and weight limits for internal B–2 Spirit bomber carriage and external F–35 Lightening II fighter carriage. This demonstration will build on the X–51 success and will include a tactically compliant engine start capability and launch from a relevant altitude.

For the other demonstration, the Air Force and DARPA will seek to develop technologies and demonstrate capabilities that will enable transformational changes in prompt, survivable, long-range strike against using the Tactical Boost Glide (TBG) concept. The objective of the TBG effort is to develop and demonstrate the critical technologies that will enable an air launched tactical range, hypersonic boost-glide missile. Both efforts will build upon experience gained through recent hypersonic ve-

hicle development and demonstration efforts supported by DARPA and the Air Force. These demonstrations are traceable to an operationally relevant weapon that could be launched from existing aircraft. Technology and concepts from these efforts will provide options for an operational weapon system for rapidly and effectively prosecuting targets in highly contested environments.

Autonomy

Analysis of these future operating environments has also led the Air Force to invest in game-changing advances in autonomous systems. Autonomous systems can extend human reach by providing potentially unlimited persistent capabilities without degradation due to fatigue or lack of attention. The Air Force S&T Program is developing technologies that realize true autonomous capabilities including those that advance the state-of-the-art in machine intelligence, decisionmaking, and integration with the warfighter to form effective human-machine teams.

The greater use of autonomous systems increases the capability of U.S. forces to execute well within the adversaries' decision loops. Human decision-makers intelligently integrated into autonomous systems enable the right balance of human and machine capability to meet Air Force challenges in the future. The Air Force S&T Program invests in the development of technologies to enable warfighters and machines to work together, with each understanding mission context, sharing understanding and situation awareness, and adapting to the needs and capabilities of the other. The keys to maximizing this human-machine interaction are: instilling confidence and trust among the team members; understanding of each member's tasks, intentions, capabilities and progress; and ensuring effective and timely communication. All of which must be provided within a flexible architecture for autonomy, facilitating different levels of authority, control and collaboration. Current research is focused on understanding human cognition and applying these concepts to machine learning. Efforts develop efficient interfaces for an operator to supervise multiple unmanned air systems (UAS) platforms and providing the ISR analyst with tools to assist identifying, tracking, targets of interest.

Autonomy also allows machines to synchronize activity and information. Systems that coordinate location, status, mission intent, and intelligence and surveillance data can provide redundancy, increased coverage, decreased costs and/or increased capability. Research efforts are developing control software to enable multiple, small UASs to coordinate mission tasking with other air systems or with ground sensors. Other research efforts are developing munition sensors and guidance systems that will increase operator trust, validation, and flexibility while capitalizing on the growing ability of munitions to autonomously search a region of interest, provide additional situational awareness, plan optimum flight paths, de-conflict trajectories, optimize weapon-to-target orientation, and cooperate to achieve optimum effects.

Finally, before any system is fielded, adequate testing must be conducted to demonstrate that it meets requirements and will operate as intended. As technologies with greater levels of autonomy mature, the number of test parameters will increase exponentially. Due to this increase, it will be impractical to verify and validate autonomous system performance, cost-effectively, using current methods. The Air Force is developing test techniques that verify the decisionmaking and logic of the system and validate the system's ability to appropriately handle unexpected situations. Efforts are focused at the software-level and build to overall system to verify codes are valid and trustworthy. The Air Force will demonstrate the tools needed to ensure autonomous systems operate safely and effectively in unanticipated and dynamic environments.

Directed Energy

With a uniquely focused directorate within AFRL, the Air Force is in a leading position in the game-changing area of directed energy. These technologies, including high powered microwave (HPM) and high energy lasers (HELs), can provide distinctive and revolutionary capabilities to several Air Force and joint mission areas. Laser technologies are rapidly evolving for infrared seeker jamming, secure communications in congested and jammed spectrum environments, space situational awareness, and vastly improved ISR and target identification capabilities at ever increasing ranges. To get HELs to a weapon system useful to the Air Force, our S&T program invests in research in laser sources from developing narrow line width fiber lasers to scaling large numbers of fiber lasers with DARPA and MDA. Since HEL devices are not sufficient for a weapon, the Air Force directed energy research also includes beam control, atmospheric compensation, acquisition, pointing, tracking, laser effects, and physics based end-to-end modeling and simulation. The Air Force also funds the High Energy Laser Joint Technology Office (HEL JTO) which supports all of the services by being the key motivator of high power laser devices such

as the successful 100 kilowatt, lab-scale Joint High Power Solid State Laser (JHPSSL) and other funding many smaller successes. The current primer program, which is jointly funded with core Army and Air Force funds, is the Robust Electric Laser Initiative (RELI). The initiative funds efforts to develop designs for efficient and weaponizable solid state lasers with options leading to a 100 kilowatt laser device.

Our HPM S&T will complement kinetic weapons to engage multiple targets, neutralizing communication systems, computers, command and control nodes, and other electronics, with low collateral damage for counter-anti-access/area denial in future combat situations. The Air Force is using the results of from the highly successful Counter-Electronics High Power Microwave Advanced Missile Project (CHAMP) Joint Capabilities Technology Demonstration (JCTD) to inform an effort known as Non-Kinetic Counter Electronics (NKCE). NKCE is currently in pre-Alternative of Alternatives (AoA) phase, with an AoA potentially starting in fiscal year 2015. The AoA will examine the cost and performances for kinetic, non-kinetic, and cyber options for air superiority and seeks to have a procured and operational weapon system to support the targets and requirements of the Combatant Commanders in the mid-2020 timeframe. In parallel, the Air Force S&T Program is continuing HPM research and development to provide a more capable and smaller counter-electronics system that can fit onto a variety of platforms.

The DOD directed energy research community is highly integrated and the Air Force leverages the work of other agencies. For example, the Air Force is working with the Missile Defense Agency on integrated electro-optical/infrared pulsed-laser targeting to enhance situational awareness and increase survivability by enabling the use of legacy weapons in the 2016 timeframe. In addition, the Air Force is partnering with DARPA on the Demonstrator Laser Weapon System, a ground-based fully integrated laser weapon system demonstration over the next 2 fiscal years and an Air-to-Air Defensive Weapon Concept.

Fuel Efficiency Technologies

For the longer term reduction in energy demand, the Air Force is investing in the development of adaptive turbine engine technologies which have the potential to reduce fuel consumption while also increasing capability in anti-access/area denial environments through increased range and time-on-station. The Air Force has several priority efforts as part of the DOD's Versatile Advanced Affordable Turbine Engine (VAATE) technology program. VAATE is a coordinated Army, Navy, and Air Force plan initiated in 2003 to develop revolutionary advances in propulsion system performance, fuel efficiency and affordability for the DOD's turbine engine powered air platforms.

The initial effort, Adaptive Versatile Engine Technology (ADVENT), began in fiscal year 2007 and is set to complete this year. General Electric is currently in final testing of the ADVENT engine technologies which include a next generation high pressure ratio core and an adaptive fan in a third stream engine architecture.

The Adaptive Engine Technology Development (AETD) program, our accelerated follow-on adaptive engine effort for the combat Air Force, is progressing very well. The objective of AETD is to fully mature adaptive engine technologies for low risk transition to multiple combat aircraft alternatives ready for fielding as soon as the early 2020's. The effort will deliver a preliminary prototype engine design, substantiated by major hardware demonstrations that can be tailored to specific applications when the DOD is ready to launch new development programs. The overarching goal of AETD is to mature adaptive engine technologies so that these programs can launch with significantly lower risk than previous propulsion development programs.

The High Energy Efficient Turbine Engine (HEETE) S&T effort is our flagship large engine effort under the VAATE technology program. The HEETE effort's primary objective is to demonstrate engine technologies that enable a 35 percent fuel efficiency improvement versus the VAATE year 2000 baseline, or at least 10 percent beyond current VAATE technology capabilities being demonstrated in the ADVENT program.

The Air Force Research Laboratory and industry have conducted a number of HEETE payoff studies that show significant potential benefits to future transport and ISR aircraft (e.g., 18 percent to 30 percent increase in strategic transport range, 45 percent to 60 percent increase in tactical transport radius, and 37 percent to 75 percent increase in ISR UAV loiter time). A study of Air Force's fleet fuel usage showed that introduction of HEETE-derived engines into the mobility and the tanker fleet would enable fuel savings of approximately 203 million gallons per year by the mid-2030's.

Investments in these efforts help us reduce energy demand, bridge the "valley of death" between S&T and potential acquisition programs, and help maintain the U.S. industrial technological edge and lead in turbine engines.

ENABLING TECHNOLOGIES

In addition to these game-changing technologies, the Air Force S&T Program also invests in many enabling technologies to facilitate major advances and ensure maximum effectiveness in the near-, mid-, and far term:

Cyber

Operations in cyberspace magnify military effects by increasing the efficiency and effectiveness of air and space operations and by helping to integrate capabilities across all domains. However, the cyberspace domain is increasingly contested and/or denied and the Air Force faces risks from malicious insiders, insecure supply chains, and increasingly sophisticated adversaries. Fortunately, cyberspace S&T can provide assurance, resilience, affordability, and empowerment to enable the Air Force's assured cyber advantage.

In 2012, the Air Force developed Cyber Vision 2025 which described the Air Force vision and blueprint for cyber S&T spanning cyberspace, air, space, command and control, intelligence, and mission support. Cyber Vision 2025 provides a long-range vision for cyberspace to identify and analyze current and forecasted capabilities, threats, vulnerabilities and consequences across core Air Force missions in order to identify key S&T gaps and opportunities. The Air Force's cyber S&T investments for fiscal year 2015 are aligned to the four themes identified in Cyber Vision 2025: Mission Assurance, Agility and Resilience, Optimized Human-Machine Systems, and Foundations of Trust.

Air Force S&T efforts in Mission Assurance seek to ensure survivability and freedom of action in contested and denied environments through enhanced cyber situational awareness for air, space, and cyber commanders. Current research efforts seek to provide dynamic, real-time mapping and analysis of critical mission functions onto cyberspace. This analysis includes the cyber situation awareness functions of monitoring the health and status of cyber assets, and extends to capture how missions flow through cyberspace. This work seeks to provide commanders with the ability to recognize attacks and prioritize defensive actions to protect assets supporting critical missions. Other research efforts develop techniques to measure and assess the effects of cyber operations and integrate them with cross-domain effects to achieve military objectives.

Research in Agility and Survivability develops rapid and unpredictable maneuver capabilities to disrupt the adversaries' cyber "kill chain" along with their planning and decisionmaking processes and hardening cyber elements to improve the ability to fight through, survive, and rapidly recover from attacks. Air Force S&T efforts are creating dynamic, randomizable, reconfigurable architectures capable of autonomously detecting compromises, repairing and recovering from damage, and evading threats in real-time. Cyber resiliency is enhanced through an effective mix of redundancy, diversity, and distributed functionality that leverages advances in virtualization and cloud technologies.

The Air Force works to maximize the human and machine potential through the measurement of physiological, perceptual, and cognitive states to enable personnel selection, customized training, and (user, mission, and environment) tailored augmented cognition. S&T efforts develop visualization technologies to enable a global common operational picture (COP) of complex cyber capabilities that can be readily manipulated to support Air Force mission-essential functions (MEFs). Other efforts seek to identify the critical human skills and abilities that are the foundation for superior cyber warriors and develop a realistic distributed network training environment integrated with new individualized and continuous learning technologies.

The Air Force is developing secure foundations of computing to provide operator trust in Air Force weapon systems that include a mix of embedded systems, customized and militarized commercial systems, commercial off-the-shelf (COTS) equipment, and unverified hardware and software that is developed outside the United States. Research into formal verification and validation of complex, large scale, interdependent systems as well as vulnerability analysis, automated reverse engineering, and real-time forensics tools will enable designers to quantify the level of trust in various components of the infrastructure and to understand the risk these components pose to the execution of critical mission functions. Efforts to design and build secure hardware will provide a secure root-of-trust and enable a more intelligent mixing of government off-the-shelf (GOTS) and COTS components based on the systems' security requirements.

Cognitive Electronic Warfare

With the highly contested future EW environment, we have focused S&T efforts on creating the ability to rapidly respond to threats. This is accomplished by developing the analytic ability to understand a complex threat environment and determine the best combination of techniques across all available platforms. In addition, leveraging cognitive and autonomy concepts improve the cycle time between emergence of a threat and development of an effective response. This system-of-systems solution approach is implemented in a physics based interactive simulation capability to evaluate novel concepts. The Air Force is also developing technologies to enhance survivability and improve situational awareness in the electro-optical (EO)/infrared (IR) and radio frequency (RF) warning and countermeasures area. New electronic components (antennas, amplifiers, processors) will improve the ability to detect threats with emphasis on advanced processing and software to assess threats in a crowded RF environment. This includes solutions to detect and defeat infrared and optical threats. These will enable protection against autonomous seekers using multi-spectral tracking.

Space Situational Awareness/Space Control

The ability to counter threats, intentional or unintentional, in the increasingly congested and contested space domain begins with Space Situational Awareness (SSA). The SSA S&T investments needed to maintain our core Space Superiority and Command and Control missions in such an environment are substantial and include research in Assured Recognition and Persistent Tracking of Space Objects, Characterization of Space Objects and Events, Timely and Actionable Threat Warning and Assessment, and Effective Decision Support through Data Integration and Exploitation. The Air Force works across these areas in cooperation with the DOD, intelligence community, and industry.

To help build a holistic national SSA capability, the Air Force's S&T investment is designed to exploit our in-house expertise to innovate in areas with short-, mid- and long-term impact that are not already being addressed by others. Examples include working with federally Funded Research and Development Centers (FFRDCs) and academia to attack the deep space uncorrelated target association problem to improve custody of space objects and reduce the burden on the space surveillance network; better conjunction assessment and re-entry estimation algorithms to reduce collision probabilities and unnecessary maneuvers; and infrared star catalog improvement to ease observation calibrations. These products have recently transitioned to national SSA capabilities. Advanced component technologies developed with industry include visible focal plane arrays, deployable baffles and lenses to meet performance, and cost and weight requirements for future space-based surveillance systems.

As part of the Air Force Research Laboratory's long history of proving new technologies in relevant environments, the Automated Navigation and Guidance Experiment for Local Space (ANGELS) program examines techniques to provide a clearer picture of the environment around our vital space assets through safe, automated spacecraft operations above Geosynchronous Earth Orbit (GEO). Equipped with significant detection, tracking and characterization technology, ANGELS will launch in 2014. It will maneuver around its booster's upper stage and explore increased levels of automation in mission planning and execution, enabling more timely and complex operations with reduced footprint. Additional indications and warning work focuses on change detection and characterization technologies to provide key observables that improve response time and efficacy.

Satellite Resilience

Our Nation and our military are heavily dependent on space capabilities. With an operational space domain that is becoming increasingly congested, competitive and contested, the Air Force has seen the need for development of technologies to increase resilience of our space capabilities. The satellites upon which we rely so heavily must be able to avoid or survive threats, both man-made and natural, and to operate through and subsequently quickly recover should threat or environmental effects manifest. To this end, the Air Force S&T Program has increased technological investment in tactical sensing and threat warning, reactive satellite control, and hardening.

Satellites today are equipped with a wide range of sensors, that, if exploited in new ways and/or coupled with new hosted threat sensing technologies could yield significant increases to tactical sensing and threat warning. The Air Force pursues a range of internally-focused health and status sensing (e.g. structural integrity, thermal, cyber) and externally focused object or phenomena sensing (e.g. space environment, threat sensing, directed energy detection) technologies, and a range of data

fusion approaches to maximize the timeliness and confidence of that warning. While tactical warning is vital, it is only immediately helpful when a satellite is able to tactically respond in some way to avoid a threat or minimize its effects. Any choice of a response requires some means of reconciling warning with viable courses of action available. The Air Force focuses on efforts specifically dedicated to tailoring satellite control based on tactical warning inputs. Finally, hardening technologies refers to a range of both passive and active capabilities that, when selected and executed, could result in threat avoidance, lessening their effects or recovering lost capability more quickly. For example, for particular types of threats, dynamic configuration changes, optical protection, cyber quarantine, dynamic thermal management or possibly maneuvers might achieve the desired protection.

Precision Navigation and Timing

Most U.S. weapon systems rely on the Global Positioning System (GPS) satellites to provide the required position navigation and timing (PNT) to function properly. This reliance has created a vulnerability which is being exploited by our adversaries through development of jammers to degrade access to the GPS signals. For success in the long term, Air Force S&T is improving the robustness of military GPS receivers and also developing several non-GPS based alternative capabilities including exploitation of other satellite navigation constellations, use of new signals of opportunity, and incorporation of additional sensors such as star trackers and terrain viewing optical systems. These receivers provide new navigation options with different accuracy depending on available sensors and computational power. Rapid progress is being made on advanced Inertial Measurement Units based on cold atom technologies. These units have the potential to provide accurate PNT for extended periods without any external update. Together, these approaches will provide future options to enable the Air Force mission to continue in contested and denied environments.

Assured Communications

Assured communications are critical to the warfighter in all aspects of the Air Force core missions. The Air Force S&T Program is developing technologies to counter threats to mission performance, such as spectrum congestion and jamming, and to maintain or increase available bandwidth through access to new portions of the radio frequency spectrum, alleviating pressure on DOD spectrum allocations. Future ability to use new spectrum will increase DOD communications architecture capacity and affordability, by requiring fewer expensive, high capacity gateways. Additional bandwidth will allow improved anti-jam communications performance and higher frequency communications, which will reduce scintillation losses for nuclear command and control (C2). The performance enhancements would directly improve the ability of remotely-piloted aircraft to transmit images and data (ISR) and improve command and control assurance.

Efforts in Assured Communications include the Future Space Communications effort which includes research to characterize and provide new spectrum for future military space communications through the W/V-band Space Communications Experiment (WSCE). WSCE will characterize and model the atmospheric effects of upper V-band and W-band (71–76 GHz and 81–86 GHz) signal transmission. Space-based data collection and atmospheric attenuation model development is necessary to provide the statistics necessary to design a future satellite communications architecture that will allow use of the currently empty V- and W-band spectrum.

Long Range Sensing

For the past decade the Air Force has provided near persistent ISR for Combatant Commanders conducting operations in the uncontested air environments of Iraq and Afghanistan. We do not see the appetite for ISR waning in the future. However, the ability to perform effective sensing in anti-access/area denial and contested environments is threatened by many new and different challenges rarely seen during the past 10 years of permissive environment operations. In the past, airborne collection platforms conducted airborne ISR outside of the lethal range of air defense systems. Today, however, the modern and evolving foreign Integrated Air Defense Systems (IADS) of our adversaries have increased lethality and significantly improved engagement capabilities which will force ISR aircraft to fly at longer stand-off distances. The effectiveness of current precision weapons will be reduced with distance limiting the ability to accurately detect, identify and geo-locate targets.

The Air Force S&T Program is focused on significantly improving our sensing ability to adequately address the challenges of extended range ISR collection. The efforts include: 1) next generation RF sensing for contested spectrum environments in which long stand-off sensing is primarily focused on all-weather ISR using traditional active radar modes at ranges of greater than 100 miles; 2) passive RF Sensing

in which signals of opportunity are exploited to detect, identify and locate targets through the use of passive multi-mode and distributed multi-static techniques; 3) laser radar sensing focused on enhancing target identification through the use of synthetic aperture laser radar and also addressing high resolution wide-area three dimensional imaging through advancements in direct detection radar; and 4) passive EO/IR sensing to enhance capabilities to detect and track difficult targets, improve target identification at long standoff ranges and perform material identification through advancing hyperspectral and stand-off high resolution imaging technology.

Live, Virtual, and Constructive

The Air Force continues to develop and demonstrate technologies for Live, Virtual, and Constructive (LVC) operations to maintain combat readiness. The training need for LVC is real while training costs are increasing and threat environments are complex. In particular, realistic training for anti-access/area-denial environments is not available. During a recent demonstration of LVC capability for tactical forces at Shaw AFB, South Carolina, AFRL LVC research capability was integrated in operations with an F–16 Unit Training Device (a virtual simulator) to simultaneously interoperate with a mix of live F–16 aircraft, other virtual simulations, and high fidelity computer-generated constructive players. This mix of players enabled the real time and realistic portrayal and interaction of other strike package assets and aggressor aircraft with a level of complexity that could not be achieved if limited to live assets, given the expense and availability of them to support the scenarios. LVC S&T has the capability to provide greater focused training for our warfighters across a range of operational domains such as tactical air, special operations, cyber, ISR, and C2. The Air Force is exploring a 5th generation LVC Proof of Concept set of demonstrations that would validate the requirements for a formal program of record for LVC.

Basic Research

The development of revolutionary capabilities requires the careful investment in foundational science to generate new knowledge. Our scientists discover the potential military utility of these new ideas and concepts, develop this understanding to change the art-of-the-possible and then transition the S&T for further use. Air Force basic research sits at the center of an innovation network that tracks the best S&T in the DOD, with our partners in the Army, the Navy, DARPA, and the Defense Threat Reduction Agency (DTRA), while monitoring the investments and breakthroughs of the NSF, NASA, NIST, and the Department of Energy. Air Force scientists and engineers watch and collaborate with the best universities and research centers from around the world in open, publishable research that cuts across multiple scientific disciplines aligned to military needs.

For example, Air Force basic research played a role in the Air Force's successful CHAMP technology demonstration discussed earlier. While the CHAMP demonstration required extensive applied research and advanced technology development, fundamental basic research investment in both supercomputers and computational mathematics provided a virtual prototyping capability called Improved Concurrent Electromagnetic Particle-In-Cell (ICEPIC) for directed energy concepts to Air Force researchers. This allowed new ideas to be studied effectively and affordably on the computer without costly manufacture for every iteration of the technology. Virtual prototyping was a critical enabling technology, and resulted from nearly two decades of steady, targeted investments in fundamental algorithms that then transitioned to a capability driving technology development in Air Force laboratories and in industry.

Manufacturing Technologies

A key cross-cutting enabling technology area is in developing materials, processes, and advanced manufacturing technologies for all systems including aircraft, spacecraft, missiles, rockets, ground-based systems and their structural, electronic and optical components. The fiscal year 2015 Air Force S&T Program emphasizes materials work from improved design and manufacturing processes to risk reduction through assessing manufacturing readiness.

The Air Force's investment in additive manufacturing technologies offers new and innovative approaches to the design and manufacture of Air Force and DOD systems. Additive manufacturing, or the process of joining materials to make objects from 3D model data layer by layer, changes the conventional approach to design, enabling a more direct design to requirements. As opposed to subtractive processes like machining, additive manufacturing offers a whole new design realm in which geometric complexity is not a constraint and material properties can be specifically located where needed. As with the insertion of all advanced materials and processes,

the Air Force strives to ensure appropriate application and proper qualification of additive manufacturing for warfighter safety and system performance.

Currently, the Air Force is invested in more than a dozen programs ranging from assisting in major high-Technology Readiness Level (TRL) qualification programs to mid-TRL process improvement programs, to low-TRL process modeling and simulation programs. Overall, we have established a strategic program to quantify risk for implementation and to advance the understanding of processing capabilities. We have identified multiple technical areas that require Air Force investment and are developing an initiative that integrates pervasive additive manufacturing technologies across Air Force sectors, spanning multiple material classes from structural, metallic applications to functional, electronic needs.

The Air Force leverages its additive manufacturing resources and interests with the Administration's National Network for Manufacturing Innovation (NNMI) to support the acceleration of additive manufacturing technologies to the U.S. manufacturing sector to increase domestic competitiveness. In fiscal year 2013, the Air Force played a key role in supporting the NNMI National Additive Manufacturing Innovation Institute called "America Makes." The Air Force, on behalf of the Office of the Secretary of Defense, led an interagency effort, which included DOD, DOE, DOC/NIST, NASA, and NSF, to launch a $69 million public-private partnership in Additive Manufacturing.

Cooperatively working with the private partner team lead, the Air Force helped "America Makes" achieve significant accomplishments in its first year. After opening it headquarters in Youngstown, Ohio in September 2012, the "America Makes" consortium has grown to approximately 80 member organizations consisting of manufacturing companies, universities, community colleges, and non-profit organizations. A shared public-private leadership governance structure, organizational charter, and intellectual property strategy were implemented and two project calls were launched in Additive Manufacturing and 3D printing technology research, discovery, creation, and innovation. So far, more than 20 projects totaling approximately $29 million and involving more than 75 partners have been started covering a broad set of priorities including advances in materials, design and manufacturing processes, equipment, qualification and certification, and knowledge base development. "America Makes" serves as an example for future NNMI institutes and the Air Force has provided support to establish two additional DOD sponsored institutes of manufacturing innovation.

The Air Force Manufacturing Technology program continues to lead the way in developing methods and tools for Manufacturing Readiness Assessments and continues to lead assessments on new technology, components, processes, and subsystems to identify manufacturing maturity and associated risk. Increasing numbers of weapon system prime contractors and suppliers have integrated Manufacturing Readiness into their culture which aids in product and process transition and implementation, resulting in reduced cost, schedule and performance risk. Benefits from the advanced manufacturing propulsion initiative continue to accrue in the form of reduced turbine engine cost and weight through advanced manufacturing of light weight castings and ceramic composites and improved airfoil processing. Advanced next generation radar and coatings affordability projects continue to reduce cost and manufacturing risk to systems such as the F–22 and F–35 aircraft. The Air Force Manufacturing Technology investment continues to make a significant impact on the F–35 program in particular, driving down life cycle costs by over $3 billion, with a number of ongoing projects that will benefit multiple F–35 program Integrated Product Teams.

The Air Force is also leveraging basic research efforts to improve sustainment of legacy systems. The "Digital Twin" concept combines the state-of-the-art in computational tools, advanced sensors, and novel algorithms to create a digital model of every platform in the fleet. Imagine a world where instead of using fleet averages for the maintenance and sustainment of an airframe, there is a computer model of each plane that records all the data from each flight, integrates the stress of the flights into the history of the actual materials on the platform, and continually checks the health of vital components. Thus, the computer model mimics all the missions of the physical asset, thereby allowing us to do maintenance exactly when required. This is the airplane equivalent of individualized medicine, making sure that each individual asset of the Air Force is set to operate at peak performance. Interdisciplinary basic research in material science, fundamental studies in new sensors and novel inquiry into new, transformational computer architecture enable the Digital Twin concepts. These foundational studies are tightly integrated with applied research, both in the Air Force Research Laboratory as well as efforts in NASA, to drive forward the S&T to permit breakthroughs in affordable sustainment.

RAPID INNOVATION PROGRAM AND SMALL BUSINESS INNOVATION RESEARCH

The Air Force recognizes small businesses are critical to our defense industrial base and essential to our Nation's economy. The U.S. relies heavily on innovation through research and development as the small businesses continue to be a major driver of high-technology innovation and economic growth in the U.S. We continue to engage small businesses through the Rapid Innovation Program, and the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs.

The Rapid Innovation Program has been an excellent means for the Air Force to communicate critical needs and solicit vendors to respond with innovative technology solutions. The program provides a vehicle for businesses, especially small businesses, to easily submit their innovative technologies where they feel it will best meet military needs. The Air Force benefits from the ability to evaluate proposed innovative technologies against critical needs, and selecting the most compelling for contract award. The response to the program has been overwhelming, and instrumental to the transition of capability by small businesses. Over the last 3 years, the Air Force has received over 2,200 white paper submissions from vendors offering solutions to critical Air Force needs. We have awarded over 60 projects directly to small businesses and anticipate awarding another 25 by the end of this fiscal year.

Projects from the fiscal year 2011 Rapid Innovation Program are now maturing and showing great promise. For example, one project developed a handheld instrument for quality assurance of surface preparation processes used in manufacturing of the F–35 aircraft. Current F–35 aircraft manufacturing processes require manual testing of 30,000 nut plates on each plane to ensure correct bonding of materials. The current failure rate is averaging 1 percent or 300 nut plates. Each failure requires individual re-preparation and re-bonding with supervisory oversight. The Rapid Innovation Program project handheld device will significantly reduce the failure rate of adhesively bonded nut plates. In turn, this will reduce rework and inspection costs, increase aircraft availability, assist Lockheed Martin in achieving its target production rate, and reduce repetitive injury claims from employees. Lockheed Martin has been very closely monitoring this technology and will be completing a return-on-investment review in the coming months following prototype evaluation.

The Air Force continues to collaborate with other Federal agencies and Air Force acquisition programs to streamline our SBIR and STTR processes. We are also collaborating with the Air Force's Small Business office (SAF/SB) to implement the provisions of the reauthorization and to assist in maximizing small business opportunities in government contracts while enhancing the impact and value of small businesses.

For example, to improve the effectiveness of SBIR investments, the Air Force Research Laboratory has started to strategically bundle, coordinate, and align Air Force SBIR topics against top Air Force priorities identified by Air Force Program Executive Officers (PEO). In the Fall of 2013, the Laboratory began a pilot effort with the Air Force Program Executive Officer for Space to focus the combined investments of approximately 45 SBIR Phase I awards and 15 Phase II SBIR awards on the identified, top priority challenge of transforming our military space-based PNT capabilities.

In conjunction with this strategic initiative, the Air Force is also energizing efforts to seek out and attract non-traditional participants, which are small businesses with skills, knowledge and abilities relevant to the bundled topics, in SBIR awards but who, for various reasons, do not routinely participate in the SBIR proposal process. This strategic concentration of small business innovation against top priorities will ultimately enhance the transitioning of small business innovation, raise the visibility and importance of those investments, and take advantage of the Nation's small business innovation. If proven successful, the Air Force will begin to institutionalize it as a model for organizing and aligning SBIR topics against other top priority issues.

One recent SBIR project developed innovative low profile and conformal antennas to allow air platforms, including small Remotely Piloted Aircraft (RPA), to operate more aerodynamically and ground vehicles to operate more covertly in areas where Improvised Explosive Devices (IEDs) are a threat. The wideband low profile antenna assembly for vehicle Counter Radio Controlled IED Electronic Warfare (CREW) systems operates efficiently from VHF to S-band, and at a height of less than 3 inches, greatly reduces visual signature. The wideband conformal antenna technologies developed for RPA systems operate from UHF through S-band and minimize the number of required antennas, significantly reducing weight and aerodynamic drag.

WORLD CLASS WORKFORCE

Maintaining our U.S. military's decisive technological edge requires an agile, capable workforce that leads cutting-edge research, explores emerging technology areas, and promotes innovation across government, industry and academia. Nurturing our current world class workforce and the next generations of science, technology, engineering, and mathematics (STEM) professionals is an Air Force, DOD and national concern. We must be able to recruit, retain and develop a capable STEM workforce in the face of worldwide competition for the same talent.

The Air Force continues to focus on developing technical experts and leaders who can provide the very best research and technical advice across the entire lifecycle of our systems, from acquisition, test, deployment and sustainment. After yielding success since 2011, the original Bright Horizons, the Air Force STEM Workforce Strategic Roadmap, is currently being updated with new goals and objectives to reflect the current environment. The Air Force has also developed a soon-to-be-released Engineering Enterprise Strategic Plan aimed at recruiting, developing and retaining the scientist and engineer talent to meet the future need of the Air Force.

The increased Laboratory hiring and personnel management authorities and flexibilities provided by the Congress over the last several years have done much to improve our ability to attract the Nation's best talent. The Air Force is currently developing implementation plans for the authorities most recently provided in the fiscal year 2014 National Defense Authorization Act. The ability to manage Laboratory personnel levels according to budget will allow us to be more agile and targeted in hiring for new and emerging research areas. The Air Force Research Laboratory recruits up-and-coming, as well as seasoned, scientists and engineers, including continuing a vibrant relationship with Historically Black Colleges and Universities and Minority Serving Institutions (HBCU/MI), who conduct research projects, improve infrastructure, and intern with the Air Force Research Laboratory in support of the Air Force mission.

The Air Force also leverages the National Defense Education Program (NDEP) Science Mathematics and Research for Transformation (SMART) Program that supports U.S. undergraduate and graduate students pursuing degrees in 19 STEM disciplines. The Air Force provides advisors for the SMART scholars, summer internships, and post-graduation employment opportunities. The Air Force has sponsored 523 SMART scholars during the past 8 years, and of the 315 scholars that have completed the program, 88 percent are still working for the Air Force, 9 percent are getting advanced degrees, and 3 percent have left due to various reasons including furlough and government funding uncertainty. The Air Force identified 110 Key Technology Areas essential for current and future support to the war fighter, which we used for selecting academic specialties for SMART scholars. SMART Scholars are an essential recruitment source of employees to enable key technology advances and future STEM leaders.

Sequestration and fiscal uncertainty in fiscal year 2013 caused the Air Force to significantly curtail travel expenses and severely limit conference attendance. It is essential for our scientists and engineers to be fully engaged within the national and international community so this curtailment disproportionately impacted the S&T community. We have worked with Air Force leadership to solve these issues and establish policies allowing greater flexibility for this mission imperative in 2014 and beyond. We can recover from the 1 year (2013) of non-participation in the greater S&T national and international community. However, severe travel restrictions over the long term could undermine the Air Force's ability retain top talent.

The Air Force has effectively used the authority provided by Section 219 of the Duncan Hunter National Defense Authorization Act not only to increase the rate of innovation and accelerate the development and fielding of needed military capabilities but also to grow and develop the workforce and provide premier Laboratory infrastructure. For example, the Information Directorate of the Air Force Research Laboratory located in Rome, New York used funding made available by Section 219 to develop curriculum at Clarkson University. The curriculum is aligned to the Information Directorate's command, control, communications, cyber and intelligence (C4I) technology mission and provides training and development programs to Laboratory personnel. To fully utilize the new Section 219 authorities from the fiscal year 2014 National Defense Authorization Act, the Laboratory is now developing a targeted infrastructure plan to provide its scientist and engineer workforce premier laboratory facilities in its locations nationwide. Recent success in the infrastructure area includes the opening of two state-of-the-art fuze laboratories at Eglin AFB, Florida, which are enabling enhanced research and development into hardened penetration and point burst fuzing.

CONCLUSION

The threats our Nation faces today and those forecast in the future leave the U.S. military with one imperative. We must maintain decisive technological advantage. We must take lessons from the last decade of conflict and creatively visualize the future strategic landscape. We must capitalize on the opportunities found within this space.

The focused and balanced investments of the Air Force fiscal year 2015 S&T Program are hedges against the unpredictable future and provide pathways to this flexible, precise and lethal force at a relatively low cost in in relation to the return on investment. We recognize that fiscal challenges will not disappear tomorrow, and that is why we have continued to improve our processes to make better investment decisions and efficiently deliver capability to our warfighters.

Chairman Durbin, Vice Chairman Cochran, and Members of the Subcommittee, thank you again for the opportunity to testify today and thank you for your continuing support of the U.S. Air Force's S&T Program.

Senator DURBIN. Thanks, Dr. Walker.

Admiral Klunder.

STATEMENT OF REAR ADMIRAL MATTHEW L. KLUNDER, CHIEF OF NAVAL RESEARCH

Admiral KLUNDER. Good morning, Chairman Durbin, Vice Chairman Cochran, and other distinguished subcommittee members. It is an honor to report on science and technology efforts in the Department of the Navy and discuss how the President's 2015 budget request supports the Navy and Marine Corps.

We use S&T to enable your Navy and Marine Corps team to maintain the technological edge necessary to prevail in any environment where we are called to defend U.S. interests. We work with the Secretary of the Navy, the Chief of Naval Operations, and the Commandant of the Marine Corps to balance the allocation of resources between near-term innovation and long-term leap-ahead research. Our goal is to improve our warfighting capability to encounter increasingly complex threats in uncertain environments while, at the same time, addressing affordability in a serious way with our systems.

Beginning with the evolution of current systems, incremental spiral development of current technology, we move toward exploiting yet-to-be-discovered, disruptive game-changing technologies. The Naval S&T strategic plan guides our investments and it is regularly updated by Navy and Marine Corps leadership to validate the alignment of S&T with the current and future missions, priorities and requirements when they come about. It ensures S&T has long-term focus, meets near-term objectives, and makes what we do clear to decisionmakers, partners, customers, and performers. The S&T plan is currently under review and will be updated in the very near future.

We fully understand that anti-access and area denial threats continue to increase. The cyber war challenge, my colleagues have noted already, will also increase and become more complex. These are problems that are not easy to solve, but we are making progress. As I said before, we also want to get away from using $3 million weapons to defeat a $50,000 threat. We have weapons in development and being fielded that will allow us to reverse that asymmetrical cost advantage currently held by some of our adversaries. And here is really what is important to me. At the end of the day, I never want to see a sailor or a marine in a fair fight, and we are confident that we can do that in an affordable way.

These are not pie-in-the-sky science projects. They are being tested. They work. I invite you and your staffs to get hands-on experience and see them for yourselves. A number of your colleagues and your staff have already been down to Dahlgren, Virginia, the Naval Research Lab here in Anacostia where world-class scientists and civilian employees are making that happen.

The bottom line is we are constantly transitioning the results of discovery and invention and applied research into fielding prototypes, weapons, and acquisition programs of record. We were commended for the way we do that by the 2013 Government Accountability Office report cited in my testimony.

But it is not enough to build transition-effective systems. They need to be extremely affordable. An ongoing example of our success in this venue is the laser weapon system I think I have briefed some of you on before. It is part of our solid state maturation program that we have ongoing. Energy weapons, specifically directed energy weapons, offer the Navy and Marine Corps game-changing capabilities and speed-of-light engagements, deep magazines, multimission functionality, and affordable missions. Laser weapons have very low engagement costs. Right now, today, the one we are going to put on the USS *Ponce* is under a dollar, under a U.S. dollar for one round of pulsed energy. We think that is critical in our current fiscal environment. We really do. They are capable of defeating adversarial threats, including fast boats, UAV's, low-cost widely available weapons. Our laser weapon system that you are going to see this summer on the ship out in the gulf leverages advancements in commercial technology for use in a rugged, robust, prototype laser weapon capable of identifying, illuminating, tracking, and lasing the enemy's surface and air threats. The Navy is installing the LaWS system on the *Ponce* in the Arabian Gulf this year. That harsh operationally important environment we think will provide a real ideal opportunity for us to evaluate long-term system performance. The LaWS has every potential for extraordinary success. We have never missed yet on all of our targets, and in terms of fielding an effective and affordable system for our marines and sailors, we think it is an ideal concept.

There is also another one. The electromagnetic railgun is similarly poised to provide game-changing, disruptive capabilities for our long-range land attack, ballistic and cruise missile defense, and anti-surface warfare against ships and small boats. Fired by an electric pulse, no gunpowder, that railgun has the potential to launch a projectile over 110 nautical miles at a speed of over Mach 7. The projectile itself development is currently well underway, and the barrel life that we have for these guns is well on its path for over 1,000 shots for each barrel. Current research is focused on improving and increasing the repetition rate of that fire and that capability for multiple rounds per minute, and those developments are certainly available to your staffs.

We also think the pulse power that comes to feed that gun is also well on its way and it is making tremendous progress also.

The development tests that are ongoing right now at the Naval Surface Warfare Center in Dahlgren that I alluded to earlier is also at NRL, nearby in Anacostia. And along with those evaluations and the test results we have performed and saw thus far, we see this

as an integration into some of our new and existing naval vessels and platforms. As a matter of fact, we are so confident, we are going to put that on one of our joint high speed vessels here in 2016 for just checking out integration.

PREPARED STATEMENT

We will continue to duplicate these kinds of successes in other S&T areas with our innovative research and disrupted thinking, always trying to make our existing systems more effective and affordable while improving acquisition programs. Our research is both exhilarating and unpredictable. We balance a range of complementary but competing research initiatives and coordinate with my colleagues and support advances in established operational areas while also sustaining far-reaching, long-term efforts that may prove disruptive to traditional operational concepts.

I thank you again for your support and look forward to answering any questions. Thank you.

[The statement follows:]

PREPARED STATEMENT OF REAR ADMIRAL MATTHEW L. KLUNDER

INTRODUCTION

It is an honor to report on Department of the Navy (DoN) Science and Technology (S&T) and discuss how the President's fiscal year 2015 Budget supports the Navy and Marine Corps (USMC). The fiscal year 2015 Budget requests approximately $2 billion for Naval S&T. The Navy and Marine Corps use S&T to enable the Fleet/Force to maintain the technological edge necessary to prevail in any environment where we may be called to defend U.S. interests. We work with the Secretary of the Navy (SECNAV), Chief of Naval Operations (CNO) and Commandant of the Marine Corps (CMC) to balance the allocation of resources between near-term technology development and long-term research. We strive to improve affordability, communication with the acquisition community, and engage with stakeholders.

SCIENCE AND TECHNOLOGY STRATEGIC PLAN

The Naval S&T Strategic Plan guides our investments and is regularly updated by Navy and USMC leadership to validate alignment of S&T with current missions, leadership priorities, and future requirements. It ensures S&T has long-term focus, meets near-term objectives, and makes what we do clear to decision makers, partners, customers and performers. The Plan identifies nine areas that help to focus S&T to meet Navy/USMC needs: (1) Assure Access to Maritime Battlespace, (2) Autonomy and Unmanned Systems, (3) Expeditionary and Irregular Warfare, (4) Information Dominance, (5) Platform Design and Survivability, (6) Power and Energy, (7) Power Projection and Integrated Defense, (8) Total Ownership Cost, and (9) Warfighter Performance. Our goal is to move from existing systems and concepts of operations toward a warfighting capability to counter predicted threats in an increasingly complex and uncertain environment. Beginning with the evolution of current systems through incremental improvement and spiral development of known technology, we move toward exploiting yet-to-be-discovered, disruptive, game-changing technologies. The S&T Strategic Plan and focus areas are currently under review and will be updated in the near future.

IMPLEMENTING THE STRATEGY

Based on time-to-delivery and specification of need, Naval S&T can be viewed as fitting into four primary areas—Discovery and Invention (D&I), Leap Ahead Innovations (Innovative Naval Prototypes/INP), Acquisition Enablers (Future Naval Capabilities/FNC), and a Quick Reaction capability to respond to emerging requirements. Our S&T portfolio balances a range of complementary but competing initiatives by supporting advances in established operational areas—while sustaining long-term research that may prove disruptive to traditional operational concepts.

DISCOVERY AND INVENTION

Discovery and Invention (D&I) includes basic research (6.1) and early applied research (6.2) in areas essential to Naval missions, as well as emerging areas with promise for future application. D&I develops fundamental knowledge, provides a basis for future Navy/Marine Corps systems, and sustains our Scientist/Engineer workforce. D&I develops knowledge from which INP, FNC, and Quick Reaction efforts are generated and is the foundation for advanced technology.

Approximately 45 percent of ONR investments are in D&I, with roughly 60 percent of that total executed by academic and non-profit performers. D&I is peer reviewed by outside experts who independently assess scientific merit—and overseen by ONR program officers and senior leadership. Investment decisions are guided by risk, impact, significance, originality, principal investigator, and budget resources.

ONR's University Research Initiative (URI) includes the Multidisciplinary University Research Initiative (MURI), the Defense University Research Implementation Program (DURIP), and the Presidential Early Career Award for Scientist and Engineers (PECASE). MURI supports teams of researchers investigating topics that intersect multiple technical disciplines. DURIP provides grants for the purchase of instrumentation necessary to perform research essential to the Navy. PECASE recognizes achievements of young scientists/engineers and encourages them to explore professions in academia and Naval laboratories. The Basic Research Challenge funds promising research not addressed by ONR's core program. The Young Investigator Program supports scientists and engineers with exceptional promise for Naval research. Research opportunities for undergraduate and grad students, fellows, and future faculty members are provided by the Naval Research Enterprise Internship Program (NREIP), where participants work at Naval laboratories and warfare centers. The In-House Laboratory Independent Research (ILIR) and Independent Applied Research (IAR) programs sponsor critical research, while furthering the education of scientists and engineers at warfare centers. ONR also brings Historically Black Colleges and Universities and Minority Institutions (HBCU/MI) together with Naval laboratories and warfare centers to give students hands-on experience in the Naval research environment.

Supporting warfighters depends on our Science, Technology, Engineering and Mathematics (STEM) workforce—but that workforce is aging. With half of Navy science and engineering professionals retirement eligible by 2020, we face an acute shortfall in our Naval engineering, computer science and ocean engineering workforce. Production of engineers has been flat for two decades, and less in specialty fields. A complicating factor is that DoN must rely on U.S. citizens for classified work; the number of U.S. citizen STEM graduates will not keep up with domestic or international competition for the same talent. ONR evaluates STEM investments with metrics tailored to measure numbers of students and teachers, overall impact, and overall ability to achieve Naval requirements in coordination with other Federal STEM programs.

LEAP AHEAD INNOVATIONS (INNOVATIVE NAVAL PROTOTYPES)

Innovative Naval Prototypes (INP) total about 12 percent of the S&T budget. INPs are high-risk/high-payoff opportunities from D&I that are discontinuous, disruptive departures from established requirements and operational concepts that can dramatically change the way Naval forces fight, while reducing acquisition risk. Overseen by the Naval Research, Development, Testing and Evaluation (RTD&E) Corporate Board (Undersecretary of the Navy; Assistant Secretary of the Navy for Research, Development and Acquisition (ASN–RDA); Vice CNO; Assistant CMC; Director of Innovation, Test, and Evaluation and Technology Requirements; Deputy Assistant Secretary of the Navy for RDT&E; and Deputy Under Secretary of the Navy for Plans, Policy, Oversight and Integration), the goal is to prove concepts and mature technology in 4–7 years, allowing informed decisions about risk reduction and transition to acquisition programs. INP Program Managers and Deputies are from ONR and the acquisition community.

INPs include:

Integrated Topside (InTop) will enable the Navy to operate freely in the electromagnetic spectrum while denying adversaries' ability to do the same through development of multi-beam, multi-function ultra-wideband apertures and Radio Frequency (RF) equipment for all ship classes. We are developing Electronic Warfare, Information Operations, Radar, Satellite, and Line of Sight Communications using: (1) open architecture RF hardware/software to enable a broad industrial base to contribute to development of affordable systems, and (2) modular systems to enable technology to be scalable across Navy platforms and reduce logistics, training, and maintenance costs. We continue prototype tests/

demonstrations with testing by the Naval Undersea Warfare Center (NUWC) for submarine Satellite Communications (SATCOM) and by the Naval Research Laboratory (NRL) for the Surface Electronic Warfare Improvement Program (SEWIP). Accomplishments include over the air testing of the Submarine Wideband SATCOM Antenna transmitter, integration of all antennas and electronics for the Electronic Warfare/Information Operations/Line of Sight Communications Advanced Development Model, building the Low Level Resource Allocation Manager, and award of the Flexible Distributed Array Radar contract.

The Large Displacement Unmanned Undersea Vehicle (LDUUV) program is developing a reliable, fully autonomous, long endurance UUV capable of extended operation (60+ days) in cluttered littoral environments. The program has already built three vehicles and is developing the energy, autonomy and core systems to operate in a complex ocean environment near harbors, shorelines, and other high traffic locations. Key goals include doubling current air-independent UUV energy density, using open architecture to lower cost, and enabling full pier to pier autonomy in over-the-horizon operations. Achieving these goals will reduce platform vulnerability, enhance warfighter capability and safety, and close gaps in critical and complex mission areas by extending the reach of the Navy into denied areas.

The Autonomous Aerial Cargo/Utility System (AACUS) is developing intelligent, autonomous capabilities for rapid, affordable, reliable rotorcraft supply in permissive, hostile and GPS-denied settings. AACUS-enabled aircraft will be supervised by field personnel from a handheld device. Challenges include dynamic mission management and contingency planning, as well as landing execution and obstacle avoidance. AACUS has already demonstrated numerous successful flights and is designed for open system architecture to promote modularity and affordability. It could be used in logistics missions, Casualty Evacuation (CASEVAC), combat rescue, and humanitarian aid missions. S&T partners include the Air Force, Army, USMC, National Aeronautics and Space Administration (NASA), Naval Air Systems Command (NAVAIR), and other academic, private sector, and government organizations.

The Electromagnetic Railgun (EMRG) has multi-mission potential for long-range land-attack, ballistic and cruise missile defense, and anti-surface warfare against ships and small boats. Fired by electric pulse, Railgun eliminates gun propellant from magazines resulting in greater resistance to battle damage. Since 2005, launch energy has advanced by a factor of 5 (to 32 mega joules) with potential to launch projectiles 110 nautical miles. Projectile design is underway, with early prototype testing, component development, and modeling and simulation.

Barrel life has increased from tens of shots to over 400, with a program path to achieve 1000 shots. Advanced composite launchers have been strength tested to operational levels. Physical size of the pulsed power system was reduced by a factor of 2.5 through increased energy density so the system will fit in current and future surface combatants. Current research is focused on a rep-rate capability of multiple rounds per minute which entails development of a tactical prototype gun barrel and pulsed power systems incorporating advanced cooling techniques. Components are designed to transition directly into prototype systems now being conceptualized. ONR is working with Naval Sea Systems Command (NAVSEA) and the Office of the Secretary of Defense (OSD) Strategic Capabilities Office to ensure commonality and reduce the need for expensive redesign. Developmental tests are ongoing at Naval Surface Warfare Center, Dahlgren and NRL, along with evaluations of integration into new and existing Naval platforms.

Electromagnetic Railgun testing aboard a Joint High Speed Vessel (JHSV) will begin in 2016 and utilize components largely in common with those developed and demonstrated at Dahlgren. At-sea testing is one of the critical events planned in coming years to demonstrate multi-mission capability. At-sea tests capture lessons learned for incorporation into a full future tactical design and allow us to understand any potential modifications before fully integrating the technology on our ships. Further, it will gather data to support design for reliability and sustainability related to Railgun operation in a marine environment.

Finally, although similarly high-risk and disruptive, SwampWorks programs are smaller than INPs and intended to produce quick results in 1–3 years. SwampWorks efforts have substantial flexibility in planning and execution, with a streamlined approval process. Formal transition agreements are not required, but SwampWorks programs have advocates outside ONR, either from

the acquisition community or Fleet/Force. SwampWorks products are frequently inserted into Fleet/Force experimentation.

DIRECTED ENERGY ROADMAP

Development and ship integration of energy-intensive systems such as Directed Energy Weapons (DEW) (e.g. high-energy lasers (HEL) and High Powered Radio Frequency (HPRF)) and EMRG requires careful engineering. Shipboard integration considerations include space, weight, power, cooling, stability, impact on combat systems, fire control, and interfaces. Technical maturity and integration will be accomplished through a measured approach to allocation of ship services and interface with ship systems.

Navy's near-term focus is on a Solid State Laser Quick Reaction Capability (SSL–QRC), which will field a prototype system based on the Laser Weapon System (LaWS), and the Solid State Laser Technology Maturation (SSL–TM) program. The Navy plans to deploy SSL–QRC (LaWS) to the Persian Gulf aboard USS PONCE in 2014 to demonstrate the ability to meet gaps in ship self-defense against armed fast boats and unmanned aerial vehicle threats. Navy is also investigating the use of non-lethal HPRF technologies for vessel stopping and counter UAS. Development continues on Free Electron Laser technologies for long-term solutions requiring power levels beyond that which Solid State Lasers can deliver.

SSL–TM will help determine the load capacity and most effective means to integrate a HEL on surface ships such as DDG–51 and the Littoral Combat Ship. The SSL–TM goal is to demonstrate a 100–150 kilowatt Advanced Development Model (ADM) by 2016. The program will address technical challenges in rugged laser subsystems, optics suitable for maritime environments, and capability to propagate lethal power levels in the maritime atmosphere. The SSL–TM prototype will be sufficiently mature to commence an acquisition program of record.

Progress on technologies covered in the Naval DE Roadmap efforts (HEL, HPRF) and EMRG are projected to result in capabilities that meet future requirements. As part of the Navy's Two-Pass Six-Gate review process for major acquisition programs, a Gate 6 Configuration Steering Board (CSB) is conducted annually for each ship class. Once a DEW achieves maturity, the CSB reviews technology, requirements, and cost to determine if transitioning to acquisition program and incorporation in a ship class is warranted. If warranted, the CSB determines on which hull the technology will be incorporated. For technology that provides significant capability but also significant installation impact to a ship, cost/benefit will be weighed against installation during new construction. If the installation impact is less, the technology could be included as part of a back fit or post-delivery installation.

In 2013, NAVSEA developed the Naval Power Systems Technology Development Roadmap (NPS TDR). NPS TDR aligns power system developments with warfighter needs, including DEWs and energy-intensive weapons and sensors for shipboard use, to ensure that future ships are capable of accepting power and cooling loads of such systems as they are developed. The roadmap addresses new construction integration and back fit of technologies for ships in service. NPS TDR is adapted to evolving requirements from weapons and sensor system developments, as well as changes in the Navy's 30-year shipbuilding plan, and will be updated every 2 years. NPS TDR introduced the concept of an Energy Magazine to provide the required power from the ship's electrical system and interface with high powered weapons and sensors. The Energy Magazine will initially support near-term applications, such as HEL, on a legacy platform. As new systems become available, the Energy Magazine can be expanded to accommodate multiple loads by providing the appropriate power conversion and energy storage.

The Naval Directed Energy Steering Group is currently drafting a Naval DE roadmap based on the Naval DE Vision and Strategy to establish goals, principles, priorities, roles, responsibilities, and objectives regarding acquisition and fielding of DEWs by the Navy and Marine Corps. This roadmap will address the way ahead for platform requirements, as well as power and cooling necessary to support these systems.

ACQUISITION ENABLERS (FUTURE NAVAL CAPABILITIES)

Acquisition Enablers (AE) are the critical component of our transition strategy. AE consists of our Future Naval Capabilities (FNC) program, USMC Advanced Technology Development (6.3) funds, Joint Non-Lethal Weapons Directorate (6.3) funds, the Manufacturing Technology (ManTech) program, and Low Observable, Counter Low Observable funds.

FNCs are near-term (2–4 year), requirements-driven, delivery-oriented S&T projects. FNCs deliver mature technologies to acquisition sponsors for incorporation

into systems that provide new capabilities. FNCs use a collaborative process involving requirements, research, acquisition, and Fleet/Force communities to align this part of the S&T portfolio with Naval Capability Gaps identified by the Office of the Chief of Naval Operations (OPNAV) and the Marine Corps Combat Development Command (MCCDC). A gap is any capability required to achieve Naval objectives that is not achievable with current platforms, weapon systems, doctrine, organizational structure, training, materials, leadership, personnel or facilities and requires S&T investment to solve or overcome. Capability Gaps define the requirement, not how to meet it.

FNCs are aligned to functional areas called "Pillars": Sea Shield, Sea Strike, Sea Basing, FORCEnet, Naval Expeditionary Maneuver Warfare, Capable Manpower, Force Health Protection, Enterprise and Platform Enablers, and Power and Energy. FNC projects address specific gaps in each of those areas, with final prioritization approved by a 3-Star Technology Oversight Group (TOG) representing OPNAV, Marine Corps, U.S. Fleet Forces Command, ASN–RDA, and ONR. FNCs are based on D&I investments where technology can be matured from Technology Readiness Level (TRL) 3 to TRL 6 in 3–5 years. Selection takes account of related work in the Department of Defense (DOD), government agencies, industry and Naval centers of excellence. Our investments focus on the most pressing gaps, with funding changes based on successful transitions, reprioritization, new starts, and evolving Naval needs. As FNC products mature, Technology Readiness Levels (TRL) change, moving products from 6.2 to 6.3 PEs. Year one is mostly 6.2; the final year mostly 6.3—with a mix of 6.2/6.3 between. As FNC products transition from S&T to Advanced Component Development and Prototypes (6.4) and Engineering and Manufacturing Development (6.5), responsibility for continued development shifts from ONR to acquisition commands.

Approved FNC products have Technology Transition Agreements to document the commitment of the resource sponsor, acquisition program, and ONR to develop, deliver and integrate products into new or upgraded systems. Every product is measured by technical and financial milestones. All products must meet required transition commitment levels for S&T development to continue. Products that no longer have viable transition paths are terminated with residual funding used to solve problems with existing projects, or start new projects in compliance with Navy priorities, charters, business rules and development guidelines. The measure of success is whether projects meet technology requirements and exit criteria, and whether acquisition sponsors have transition funds in programs to accept and integrate FNC products. The transition status of FNC products is actively monitored on an annual basis, with products terminated if the S&T is failing or the transition plan is no longer viable. Through the end of fiscal year 2013, 216 FNC products completed S&T development (a success rate of 84 percent), with 41 FNC products terminated before completion.

Results are evaluated by a Transition Review Board (TRB) consisting of Naval Reserve Officers representing Requirements, Acquisition and S&T communities. The TRB provides an objective, independent assessment of FNC products after successful transition or termination, analyzing the causes and residual value of unsuccessful transitions and deployments. Even in case of products which do not deploy, there is significant residual value in technology that can be leveraged for follow-on S&T efforts and made available for future transitions. Nothing goes to waste.

QUICK REACTION S&T

ONR maintains quick-reaction capability for projects lasting 12–24 months that respond to immediate requirements identified by Fleet/Force or Naval leadership. TechSolutions provides short-term solutions to immediate operational and tactical requirements. Accessible via Internet and SIPRnet, TechSolutions accepts recommendations from Sailors and Marines about ways to improve mission effectiveness through the application of technology. TechSolutions uses rapid prototyping to meet specific requirements, with each project structured around definable metrics, and appropriate acquisition/test systems by integrated product teams. While neither a substitute for the acquisition process, nor a replacement for systems commands, TechSolutions prototypes deliver solutions to address immediate needs that can be easily transitioned to the Fleet/Force.

Technology development often occurs faster than DOD Planning, Programming, Budgeting and Execution (PPBE) can respond. Our Technology Insertion for Program Savings (TIPS) program provides current-year funding (inside the PPBE process), eliminating time lag in the PPBE cycle. TIPS provides up to $2 million for development efforts taking no more than 2 years, coupled with Fleet/Force support and resource sponsor commitment to fund moving the technology into the acquisi-

tion Program of Record (POR) or operating system. TIPS focuses on improvements that substantially reduce operating and support costs for warfighting systems.

In partnership with ONR, Naval Warfare Development Command (NWDC), Naval Postgraduate School, Naval War College and Marine Corps Warfighting Lab (MCWL) assess new warfighting concepts and technologies. Initiatives in support of our maritime strategy are applied, tested, analyzed and refined through war games, exercises, experiments and operational lessons learned.

GOVERNMENT ACCOUNTABILITY OFFICE (GAO) REPORT ON TECHNOLOGY TRANSITION

In the March 2013 Government Accountability Office Report, "DEFENSE TECHNOLOGY DEVELOPMENT: Technology Transition Programs Support Military Users, but Opportunities Exist to Improve Measurement of Outcomes (GAO–13–286)," GAO reported:

> ". . . the Office of Naval Research (ONR) has a well-established technology transition focus. ONR's Office of Transition manages the Future Naval Capabilities (FNC) portfolio, which is the Navy's largest transition program—for which nearly $450 million was budgeted in fiscal year 2013. The program, which was initiated in 1999, seeks to provide the best technology solutions to address operational requirements, delivering technology products to acquisition programs that enhance capabilities within a 5-year timeframe. ONR's Offices of Transition and Innovation also support rapid technology transition to the fleet, force, and acquisition communities via the Rapid Technology Transition (RTT), Technology Insertion Program for Savings (TIPS), TechSolutions (TS), and SwampWorks and Experimentation (SW/Exp) programs." (p. 9)
>
> GAO said, "The Navy uses a Transition Review Board to monitor completed projects from the Future Naval Capabilities, Rapid Technology Transition, and Technology Insertion Program for Savings programs. The board determines and reports on whether transitioned projects are utilized in systems that support Navy warfighters. The Navy determined, for example, that of the 155 technology products the Future Naval Capabilities program delivered to acquisition programs between fiscal years 2006–2011, 21 percent were subsequently deployed to fleet forces, 35 percent were still with the acquisition programs, and 44 percent failed to deploy. For projects that do not successfully deploy, the board assesses whether there are other benefits achieved, such as technologies leveraged for follow-on S&T work. The board also identifies obstacles to transition, such as loss of interest by the user or inadequacy of funding. These findings, along with a detailed one-page summary for each project, are then used to inform the Navy's annual review process. We found that by maintaining this level of tracking, the Navy is better aware of the benefits and obstacles associated with a substantial portion of their S&T portfolio, which may better inform decisions made by Navy leadership." (pp. 21–22)
>
> GAO continued, "At the program level, many program officials indicated that senior leadership engagement, particularly in providing oversight for projects through to transition, is essential to having an effective program. We found the Future Naval Capabilities program provides a good example of senior leadership positively affecting project management activities. Specifically, due to funding constraints in its fiscal year 2013 S&T budget, Navy senior leadership supported the termination of ongoing Future Naval Capabilities projects that were determined to be lower priorities so that new, higher priority projects could be pursued. Navy officials stated that this type of awareness and understanding at senior levels enables the Future Naval Capabilities program to make efficient decisions that are less likely to meet resistance and that support the highest priority projects being developed for transition opportunities. (p. 25)
>
> "Several transition programs also emphasized the relationship between "working-level" stakeholders—S&T developers and acquisition programs or warfighters in the field—when discussing the keys to technology transition. These stakeholders manage expectations throughout a project and ensure it will meet user needs. This reduces the risk of completed projects languishing because funding is not available or because user requirements have changed, or both. Some programs that we reviewed use integrated product teams, which may be composed of individuals representing the requirements, acquisition, operational, and S&T communities, among others, to facilitate continuous communication with stakeholders and ensure that transition planning is on track. In the case of the Navy, integrated product teams identify capability gaps, provide input on which S&T projects may address those gaps, assess project progress, make sure transition strategies remain valid, and confirm funding is

aligned to support transition. According to Navy officials, the results of integrated product team efforts also support information sharing across senior- and working-level stakeholders to validate development status and transition planning activities." (pp. 25–26)

GAO concluded, "We found the Future Naval Capabilities program uses technology transition agreements as management tools to increase the level of documented commitment as a project progresses over time. To accomplish this, the program has three levels for agreements that reflect the requisite knowledge available at different phases of a project. Key elements of an initial agreement include a basic project description, identification of initial exit criteria, a high-level integration strategy, and a likely transition funding source. As a project progresses, the other two levels of agreement require increasing commitment and specificity of requirements from stakeholders to develop, deliver, and integrate a Future Naval Capabilities project into an acquisition program or other form of deployment. Key elements of the second and third tier agreements involve refining and finalizing project descriptions, detailing exit criteria, providing greater specificity about the integration strategy, and providing estimates for transition costs and eventually executing transition funding. Stakeholders review the agreements annually to revalidate the commitments laid out within the document. (p.27)

"We also found Transition Commitment Level (TCL) assessment tools . . . offer another means of validating that transition programs are investing in projects that have a firm transition commitment from prospective users. These tools provide scorecards that chart how well-defined the fundamental characteristics that support a strong commitment to transition projects are at a given point in time. The Future Naval Capabilities program uses a single TCL tool that documents level of transition commitment from project start to completion." (p.27)

S&T HIGHLIGHTS

The Naval S&T portfolio includes a range of projects and programs entering or about to enter the Fleet/Force. Examples follow.

EXPEDITIONARY MANEUVER WARFARE AND COMBATING TERRORISM

Marine expeditionary forces are forward-deployed and forward-based, right-sized to respond to missions across the range of military operations from combat to Humanitarian Assistance and Disaster Relief (HADR). This is best achieved by a Middleweight Force which can launch from the sea and project power in sophisticated anti-access, area-denial (A2/AD) environments. The imperative to lighten the load for every Marine and the Marine Air-Ground Task Force (MAGTAF) is critical, requiring research in technologies that increase speed, agility and range, develop advanced materials for lighter body armor, helmets and eye protection, while reducing fuel consumption and vulnerability to Improvised Explosive Devices (IEDs) and mines. We develop over-horizon, beyond line-of-sight, restricted environment communications, and adaptable sensor systems to detect, classify, identify, locate and track low level entities in urban clutter, improve situational awareness, and enhance real time tactical decisionmaking.

Improving resilience of Marines enables them to more effectively, efficiently observe, orient, decide and act (OODA) in complex, stressful conditions. We explore technologies to provide autonomous logistics, and enhance fuel, water and maintenance self-sufficiency. On-demand, reduced logistics enable a high operational tempo, and allow the Corps to out-maneuver and dominate any enemy. Marines outperform and out-think enemies by understanding battlespace in greater detail, making decisions with greater understanding of enemy intent, and getting inside the enemy decision cycle. To achieve this, ONR created a small unit leader training framework based on codified learning models and theories to deliver technology and knowledge products for the USMC Training and Education Command (TECOM) that maximizes learning and skill acquisition at minimal cost. We invest in S&T to improve training efficiency based on cutting-edge, neuro-cognitive, psychologically-driven instructional strategies that enable Sailors and Marines to survive the brutal environment of combat, as well as retain emotional and mental health after they leave the traumatic environment.

Current S&T investments include projects to improve On-Board Vehicle Power, Advanced Remanufacturing and Sustainment Technologies, and Internally Transportable Vehicle Autonomy Conversion. Force Protection projects include development of Personal Protection Technologies, On-The-Move Detection-of-Threat Optics, the Modular Explosive Hazard Defeat System (MEHDS), and Ground Based Air De-

fense (On-the-Move). Fires projects (Advanced Ammunition and Energetics) include an Integrated Day-Night Sight, the High Reliability DPICM (Dual Purpose Improved Conventional Munition) Replacement Program, and High Performance Alloys for Weapons. Logistics applications will improve Pallet Handling and Packaging, a JP–8 Solid Oxide Fuel Cell, and Autonomous Resupply technology. Human Performance, Training and Education investments will provide an Advanced Training System for Small Unit Decision-Making, and Training to Optimize Use of Resilience Skills (TOURS). Finally, Intelligence, Surveillance and Reconnaissance projects include Night Wide Area Augmentation System (WAAS), Entity Disambiguation, and Semantic Web enablement to enhance mission-centric knowledge generation and delivery. Our S&T efforts are undertaken hand-in-glove with the Marine Corps Warfighting Laboratory at Quantico, Virginia, whose mission is to rigorously explore and assess Marine Corps concepts using an integral combination of war-gaming, concept-based experimentation, technology assessments, and analysis to validate, modify or reject the concept's viability, and identify opportunities for future force development.

COMMAND, CONTROL, COMMUNICATIONS, COMPUTERS, INTELLIGENCE, SURVEILLANCE AND RECONNAISSANCE (C4ISR)

The proliferation of anti-access, area-denial (A2/AD) capabilities among potential adversaries drives the need for technologies that assure access for Naval forces. Our challenges include the requirement to project power despite A2/AD challenges and to provide information dominance to the warfighter.

Improved decisionmaking is central to the Navy's S&T plan to provide information dominance to the warfighter. One goal is to develop a highly flexible, open architecture, information and decisionmaking capability with applications enabling operational and tactical forces to function with the same distributed information base across all warfare and mission areas. Information gathering and analysis will be largely automated and autonomously controlled so warfighters can have more time to make decisions and execute plans. A key aspect of this is our use of the electromagnetic spectrum for dominance, while denying the same to our adversaries. To this end ONR, Navy, and the other services are working to deliver hardware and software to support electromagnetic spectrum dominance in the near and far term. Capabilities are in various stages of maturity and deployment.

ONR developed software to evaluate effectiveness of new Electronic Warfare countermeasures. When the Fleet identified a requirement to improve threat awareness and assess vulnerability to anti-ship cruise missiles using organic Electronics Support Measures (ESM) sensors and radar, ONR used the same software to address the new requirement by developing a Human-Machine Interface (HMI), installing it on ships, and deploying scientists to make the new HMI sailor friendly. This gave the Task Force a clearer picture of ESM effectiveness and vulnerabilities relative to current sensors, weather, and threats—allowing them to reassign sensor coverage and move platforms to reduce vulnerabilities.

The Joint Counter Radio Controlled Improvised Explosive Device Electronic Warfare (JCREW) effort is developing flexible, dynamic system architecture to detect IED signals across the entire spectrum and provide automated responses. Unlike current technology, JCREW is designed to allow detection and communication systems to operate simultaneously.

OCEAN BATTLESPACE SENSING

To continue to dominate in the maritime environment Naval forces must be able to accurately predict and adapt to ocean, air, littoral and riverine environments on both tactical and strategic levels. Recent changes in climate conditions and extremes have created an emerging need for more accurate and longer range forecasts for DOD and Naval operations. In support of the Navy's Task Force Climate Change, the National Oceanographic Partnership Program, and in partnership with the Air Force, Department of Energy, National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration, and National Science Foundation (NSF), we invest in S&T to provide mobile autonomous environment sensing, match predictive capability to tactical requirements, develop systems that adapt to environmental variability, and integrate atmospheric and ocean models to enable better forecasting. Additional investments will provide a better understanding of surface wind impact on upper ocean dynamics and energy fluxes across ocean boundary layers, increase knowledge of high latitude Arctic environments, and enhance our ability to forecast operational conditions with longer lead times. The payoff is safer, more efficient Naval operations in maritime environments through improved immediate, seasonal and longer range forecasts.

ONR's environmental research is heavily field-oriented, employing oceanographic ships, aircraft, and autonomous air and undersea vehicles. For example, the Navy owns six University-National Oceanographic Laboratory System (UNOLS) Ocean Class Research Vessels that ONR schedules and supports in partnership with NSF. Construction of two replacement vessels is underway, with Auxiliary General Oceanographic Research Ship (AGOR) 27—Research Vessel (R/V) Neil Armstrong assigned to Woods Hole Oceanographic Institution, and AGOR 28—R/V Sally Ride assigned to Scripps Institution of Oceanography. Both are expected to begin research operations in fiscal year 2015.

In addition, we are developing rapid, standoff mine countermeasures to support unencumbered maneuver of combatants, assure access, ensure strategic mobility and sustainment, decrease mine countermeasure (MCM) hazards, and increase the standoff range of combatants from minefields. ONR experiments with sensing and autonomy technologies help small vessels to operate at night, in all weather, at higher speeds, and with less risk over large, poorly mapped riverine systems. Our Advanced Undersea Weapon System (AUWS) will deliver targeting sensors and remotely controllable or autonomous weapons into chokepoints or channels to neutralize maritime threats. ONR's Advanced Sonar Technology for High Clearance Rate MCM in the surf and autonomous minehunting payloads for Unmanned Surface Vehicles (USV), reduce timelines for detecting, identifying and clearing floating, drifting, moored and bottom mines in shallow water.

ONR supports research in acoustic propagation and scattering to improve anti-submarine wide area surveillance, detection, localization, tracking, and attack capabilities against adversary submarines in noisy, cluttered shallow water environments. We provide S&T to mitigate effects of acoustic systems on marine mammals, to improve probability of kill for undersea weapons, and to enable new undersea weapon concepts of operation. Projects include the Remote Aerial Sonar and Communications Laser (RASCL), Affordable Compact Bow Sonar for large deck surface ships, holding threat submarines at risk in forward areas, screening transiting battle groups, and providing torpedo defense for ships.

SEA WARFARE AND WEAPONS

ONR's major focus in this area is to improve surface, submarine, ground, and air platforms, as well as undersea weapon performance. S&T investments provide options for advanced electrical systems and components, and for survivable, agile, mobile, sustainable, manned and unmanned, surface and sub-surface sea platforms, and undersea weapons. Significant investments provide S&T to improve performance and affordability of the Nation's strategic submarine assets under the Ohio Replacement Program (ORP), as well as Virginia-class submarines. Our Electric Ship Research and Development Consortium enlists academic institutions to develop electric power architectures and technologies to enable use of next generation high power sensors and weapons, including directed energy weapons (DEW) systems described earlier. Investments encompass projects to transition S&T necessary to improve performance and capabilities of our current fleet of torpedoes, undersea weapons and vehicles, as well as effective countermeasures and defensive weapons to protect against undersea weapon threats. Undersea vehicle S&T includes research, development and deployment of long-endurance, air-independent power systems for unmanned undersea vehicles (UUVs). Additionally, we utilize extensive experience in surface craft design and autonomy to provide the Fleet with unmanned surface vessels (USVs) capable of operating effectively in a range of marine environments.

A key enabler of these Sea Warfare and other capabilities is S&T investment in naval materials. These investments focus on performance and affordability of advanced materials for applications such as lightweight structures, corrosion and biofouling mitigation, maintenance cost-reduction, undersea acoustics, and energy- and power-dense electrical energy conversion and storage. These efforts explore and apply fundamental materials physics to discover and engineer future materials meeting warfighting platform demands now and in the future. Consistent with this approach, our investment in Integrated Computational Materials Engineering is a key contributor to the recently established Lightweight and Modern Metals Manufacturing Initiative (LM3I).

WARFIGHTER PERFORMANCE

Warfighter Performance S&T addresses the full range of research issues involving human system interactions, medical and biological systems, and supports the SECNAV mission of protecting the safety and privacy rights of human research subjects.

Human system research helps the DoN recruit the right people, assign them to the right jobs, while ensuring they have the right skills in safe systems that are designed to support effective decisionmaking and collaboration. Our S&T investments in this area helps improve small team, platform, task force, and battle group operations by developing training technology and decision support systems that accommodate human capabilities and limits. ONR initiatives include simulation-based approaches to fleet integrated, multi-platform, multi-mission training and experimentation that enable near-real time collaboration, decisionmaking and planning across platforms and organizations.

Warfighter performance goals are to enhance performance, improve the timeliness and quality of decisionmaking, develop strategies to mitigate workload, resolve ambiguity, and reduce workload and manning, while improving situational awareness and speed of command. Training technology S&T designs virtual networked learning environments that exploit live assets, virtual simulators and artificially intelligent constructive (Live, Virtual, Constructive/LVC) entities in distributed training environments to increase individual and team skill, knowledge, expertise and experience in warfighting tasks. S&T enables the Navy and Marine Corps to effectively and affordably train in classrooms, simulated environments, and on deployment.

Medical S&T improves the health, well-being, protection and survival of personnel in undersea, shipboard and expeditionary settings. ONR develops medical equipment, diagnostic capabilities, and treatments to improve warfighter performance and resilience. ONR develops solutions for point of injury care and casualty evacuation, new approaches to mitigate risks associated with operations in extreme environments such as dive medicine, and continues to address noise induced hearing loss by reducing noise at the source, limiting exposure, and developing protective technologies.

ONR's biological research program exploits principles from nature to design, control and power autonomous systems; improve processes, materials and sensors; and develop synthetic biology tools to support the Fleet/Force. Biocentric technologies offer a variety of enabling capabilities, including bio-inspired autonomous vehicles, acoustic/seismic discrimination systems, microbial fuel cells for sustainable power, engineered plants that produce energetic material precursors, and diagnostic tools to assess the health of marine mammals.

Human subject research is critical to support the Navy and Marine Corps warfighter, training and operational capability, and Navy Medicine. Many RDT&E activities designed to respond to Fleet/Force requirements necessitate human subject participation. As part of the DoN Human Research Protection Program, ONR is responsible for implementation of human subject protections in the Navy's systems commands, operational forces, training units, and at Navy-sponsored extramural institutions. ONR reconciles the competing priorities of conducting potentially risky research involving human subjects and compliance with Federal, DOD, and DoN human protection policies.

NAVAL AIR WARFARE AND WEAPONS

ONR's Naval Air Warfare goal is to develop, demonstrate and transition technologies to expand Naval weapon system stand-off ranges and reduce engagement timelines to enable rapid, precise, assured defeat of moving land, sea and air targets. We invest in S&T to develop propulsion for high speed weapons requiring technologies associated with high acceleration, high temperature, and high strength materials. We develop advanced structural materials and corrosion protection for aircraft, improvements that enhance operational characteristics such as improved lift, and to address other requirements driven by operations in the unique maritime environment. These include kinematic and lethality enhancements to increase range and effectiveness of tactical weapons, and aided target recognition to provide the F/A–18 with advanced target identification capabilities.

NAVAL RESEARCH LABORATORY (NRL)

ONR supports the DoN corporate lab, the Naval Research Laboratory (NRL). The NRL base program develops S&T to meet needs identified in the Naval S&T Strategic Plan and sustains world class skills and innovation in our in-house laboratory. Research at NRL is the foundation that can focus on any area to develop technology from concept to operation when high-priority, short-term needs arise. NRL is the lead Navy lab for space systems, firefighting, tactical electronic warfare, advanced electronics and artificial intelligence. Among our greatest challenges is to recapitalize NRL infrastructure. I invite you to visit this facility and learn more about research undertaken there by our world-class scientists and engineers.

ONR GLOBAL

ONR has offices in London, Prague, Singapore, Tokyo and Santiago—and closely coordinates activities with the other services and Assistant Secretary of Defense (Research and Engineering). We search for emerging research and technologies to help address current Naval needs, as well as requirements for future capabilities. ONR Global establishes contacts with international S&T leaders, giving us new perspectives and helping identify trends and forecast threats. It enables us to recruit the world's scientists and engineers in partnerships to benefit the U.S. and our allies. Global includes Science Advisors who communicate Fleet/Force needs to the Naval Research Enterprise (primarily Navy labs, warfare centers, affiliated universities) to facilitate development of solutions to transition to the Fleet/Force. Participants include Naval engineers who coordinate experimentation, develop prototypes, define transition options, and collaborate with Fleet/Force to define S&T investments. Our International Science Program gives scientists from academia, government and industry opportunities to engage leading international scientists and innovators. Our technical staff helps establish collaboration between Naval scientists and their foreign counterparts, and identifies centers of excellence for Naval S&T.

CONCLUSION

The fiscal year 2015 President's budget request will enable us to continue moving toward enhanced capabilities, more effective partnership between research and acquisition, and strengthened partnerships with the Army, Air Force, DARPA and other DOD research organizations—as well as performers outside the Naval R&D system. We strive to tap into the full spectrum of discovery and accelerate the transition of appropriate technologies to civilian use. Our S&T investments represent careful stewardship of taxpayer dollars that will achieve these goals and significantly enhance the safety and performance of warfighters as they serve in defense of the United States. Thank you for your support.

Senator DURBIN. Thanks, Admiral.

I have three questions for the panel. I am going to state all three of them and anyone who feels inclined can jump in.

First question: When I go to the NIH and ask Dr. Collins, he tells me that there is a dramatic decline in NIH researchers, that they are seeing in 1982 19 percent of their researchers were under the age of 36. Today it is 3 percent. He believes that our failure to fund his agency on a regular basis has created a crisis of confidence in those who are scientists and engineers who might otherwise go into biomedical research.

I would like to know if you have seen this phenomenon in the work that you are doing.

Secondly, I would like to address an issue that is timely because it is on the floor of the Senate. We are now contemplating extending the R&D tax credit under our tax code for private companies to invest in research and development. We believe that that work is so valuable that we ought to create a tax incentive for it, and I have always voted for it because I agree with that conclusion.

However, we are running into an interesting political dilemma. There are some who say that because it is a tax cut, you do not have to pay for it. However, if you took tax dollars and spent them at your agencies or the National Institutes of Health, you have to cut spending somewhere else. I do not understand the difference.

And the basic question is this: Do you believe that the R&D tax credit is enough to sustain America's superiority when it comes to basic research or developmental research, or do you believe the Government plays a unique role or a different role that ought to be served as well by adequately funding research efforts. I think I know the answer to that question.

The third issue relates to the coordination of effort. This worries me. I have put in this budget more money, I believe, than in past years for medical research. I really intensely believe in it, and I believe the Department of Defense has proven that the money they receive can be well spent in medical research. I am interested in the coordination of medical research. I want to make sure, for example, when we have a BRAIN (Brain Research through Advancing Innovative Neurotechnologies) initiative that is shared by DARPA and NIH and other agencies, they are actually, at the beginning of this conversation, sitting down and establishing parameters and goals and methods of funding so we are not tripping over one another and wasting these precious medical research resources.

Jump ball. Dr. Prabhakar.

Dr. PRABHAKAR. Mr. Chairman, let me dive in because you talked about things that I want to discuss. I think they are very much on point.

Let me try to attack the first two questions from the following perspective. I am now at a point where I have spent half of my professional life in the public sector and half in the private sector. When I returned to Washington about a year and a half ago, I came from 15 years in Silicon Valley, most of that in venture capital. And from that perspective, let me comment on the issue of the research community in the United States, who the people are that are engaged in this enterprise, and the R&D tax credit question.

On the people issue, one of the things that really struck me, when I returned to the national security community after serving on the boards of small private companies as venture capitalists, is it was such a stark reminder that in the national security work, we really have migrated to where we connect with a very narrow part of the broader technical community. A lot of that has to do with the backgrounds of a lot who constitutes our technology community today. Over half of the Ph.D. engineers who practice in the United States today are foreign-born. The DOD does not have great ways of reaching into those communities, and I think without active efforts to reach into the research community to make those connections, recognizing that there are real security issues that have to be dealt with, we need, I think, to continue the kinds of work that all of us are doing that reach into research institutions and reach beyond just the defense community, the classic defense industrial base and the classic research labs in DOD, if we are to tap that broader human capital that is so vital to our national security needs. Number one.

On the issue of the different kinds of funding, many others have much more knowledge, and obviously, I will leave it to you all to sort out tax policy. The point I really want to underscore, though, is the question of whether private companies' access to R&D tax credits or any investments that private companies make—how those contrast to the kind of work that happens with publicly supported R&D, particularly in the Defense Department. And again, I have seen both sides of that story.

This is a national R&D ecosystem, and in an ecosystem, all the portions have to be healthy. So, yes, absolutely it matters that our companies continue to make the R&D investments which they make in order to build the next products and services that they can

sell at a profit. That is what they do. That is how the economy works. Very important but different than the public R&D investment that is made. In our cases, of course, we are making that R&D investment for national security purposes, and our portfolios are chock full of the kinds of research that simply is not going to get invested in by private companies.

Now, often we end up laying a research base. Sometimes we lay a research base that leads to much bigger private investment and then leads to, for example, all the technologies in the cell phone that you described earlier. But the reason all of us are making these investments is because it is simply not going to happen any other way, and it is vital to our Nation's needs.

Mr. SHAFFER. Sir, I would like to follow on to Arati's comments. I fully support what she said. I would like to add a little bit of data to some of that.

For the first question on researchers, across our laboratories, we have basically a bimodal distribution with a larger number of researchers around 35 to 45, a large number of researchers 55 to 65, a bathtub from the last Government drawdown. I am concerned about the future because last year across the Department we hired under 1,000 new scientists into our laboratories, compared to a normal 3,000. Furthermore, right now what we are seeing across the board is about for every three who leave, we can hire one coming back in. That is just because of the budget crisis. So I am concerned. We are gathering across the panel that you see here better metrics, but there is a problem.

The other thing I would like to comment on are the R&D tax credits. I am not going to get into taxes and tax policy, but I will tell you we are trying to make the industrial research part of what we are thinking about every day in the Department. We have made a strong emphasis on IR&D (independent research and development), but we are seeing data coming out of the industrial sector. In fact, CSIS (Center for Strategic and International Studies) issued a report yesterday that showed, with one notable exception—I am not going to get into which company—the amount of industrial IR&D over the last decade has declined fairly dramatically to the point where some of our major defense contractors are not putting much money back into R&D. And that is a concern because they are part, as Arati said, of the entire ecosystem.

Senator DURBIN. Senator Cochran.

Senator COCHRAN. Mr. Chairman, it is a pleasure to join you and other members of the committee in reviewing the testimony or presentations being made by this distinguished panel of witnesses today.

Ms. Miller, I understand coincidentally you visited the Army Corps of Engineers Research and Development Center laboratories in Vicksburg earlier this week. I would be interested in hearing your impressions of that visit. And to the extent that it is not classified, tell us what your impressions were.

Ms. MILLER. Thank you for the opportunity.

It was a great visit. I have, obviously, been working with the Corps of Engineers for a long time as my role here as DASA R&T (Deputy Assistant Secretary of the Army for Research and Technology), but this was the first time I had actually made it down to

Vicksburg. I have had a number of trips scheduled and been called off, and this time, even though they knew I was testifying on Wednesday, I said I was coming anyway. So I am here on 3 hours of sleep because we had a little bit of weather coming back into DC last night. So I apologize for that.

The Corps is very impressive. The Engineer Research and Development Center is very impressive. While I was there, they took me through a number of their major activities. They have been looking at climate change and its impact not only on the environment but on the Army in particular, how we can utilize training ranges, how it might impact BRAC (base realignment and closure), not that we want one, but if BRAC happens again, we want to be prepared to understand the impacts on the Army areas that we might choose to relocate, how it affects operations in the Army as we go forward in the future and the upsetness that might happen in the world as we see it. We talked about environmental work. We talked about nanotechnology and the fundamentals that they do there to understand the impact of new materials that the Army is looking at using before they become a problem to the environment and to the soldiers that will be using them. All that is foundational and informs the rest of our weapons development and our material development.

We also talked about high performance computing. They are the executive agent on behalf of all of the services for executing that program, which was divested from OSD (Office of the Secretary of Defense) to us 4 years ago, some very significant work there and something that I believe will underpin what we go forward with in the future.

Senator COCHRAN. Thank you very much for that overview and for the contributions that we are making across previously established boundaries in this missile defense area. There is a great deal of collaboration going on, and I commend all of the panel for the work you are doing to make sure we have the most modern capabilities to protect the security interests of our country and for your sharing of that information from time to time as we visit with you and review the budget request for the next fiscal year.

We are constrained because of the allocations, but your testimony helps us make the best choices in my view, and we should pay very careful attention to what you say to us about these very serious and important issues.

Thank you for your good work.

Senator DURBIN. Senator Shelby.

Senator SHELBY. Thank you.

We all have this chart, which Senator Durbin mentioned in his opening statement, at the hearing that Senator Mikulski called the other day, and a lot of us were there. It is disturbing the trend line going in the wrong direction on biomedical research, but it is also going the wrong direction in basic research.

For the record, could you translate that into real dollars? The trend line is bad. And China and what they are doing in investing in the future will bode well for them, maybe not for the rest of the world. But if you could translate this into dollars, that would be good for the committee, I believe, rather than just percentages.

I would like to direct my first question to Dr. Prabhakar. DARPA's involvement in the creation of the Internet is well known and well documented. Thank goodness. Thus, it comes as little surprise that the birthplace of the Internet is also leading the way in developing innovative mechanisms to protect that domain from cyber warfare attacks, which is a big concern of the business community, of the Pentagon, everything in today's world.

It is my understanding, Doctor, that DARPA is currently working to develop a cyber warfare program, which would allow DOD to create platforms to plan for and counter cyber warfare just as it would for kinetic warfare. Whatever you can talk about here in open session, would you please update this Committee on Appropriations on the status of Plan X and, more broadly speaking, how important is sustained funding for DARPA's cybersecurity efforts to this country?

Dr. PRABHAKAR. Thank you, Senator Shelby.

As I mentioned in my opening remarks, cybersecurity I think is one of the core foundations as we become increasingly reliant on information. I think we are all familiar with the challenges that our businesses and our national security enterprise face because of cyber attacks that are happening on a constant basis, some driven by nation states, some driven by organizations, and some just individuals because so many individuals around the world have at their fingertips now the ability to participate in this domain, for better or for worse, often for better, but sometimes unfortunately for worse.

We think that that cyber environment in which we are in a conflict today, that that is going to continue to escalate. Much of the conversation has been about computers and networks. Those are important to keep secure. But, of course, all of our embedded systems are also highly vulnerable. One of our researchers a couple years ago showed that they could hack the speedometer on a car. So if a speedometer on a car is vulnerable, then I think it is a good thing to realize that all of our embedded military systems are also vulnerable. Everything has a computer in it today.

So Plan X is a foundational cyber warfare program that we are building to allow us to have the visibility and the understanding of cyberspace so that we can start to deal with how cyber warfare is happening today and where it will be in the future. We think it is going to become integral to the kinetic warfighting of the future.

We want to give our senior decision-makers the ability to see what is happening in cyberspace, to plan actions, to be able to predict collateral effects, to avoid affects that they want to make sure do not happen, and then to do battle damage assessment. Those are the core capabilities.

Senator SHELBY. Is this one of DARPA's top priorities?

Dr. PRABHAKAR. Across our portfolio, it is a high priority. As you know, what we do at DARPA needs to be a balanced portfolio. Maintaining the security of our information systems is one of those high priorities.

Senator SHELBY. Doctor, it is my understanding that I am getting into the long-range anti-ship missile. It is my understanding that on April 22, a few weeks ago, DARPA demonstrated five key technologies to the Secretary of Defense at the Pentagon. Among

the five technologies exhibited was DARPA's long-range anti-ship missile which seeks to pierce through advance air defense systems and engage enemy warships from a long range, which is smart.

Could you discuss the importance of continuing to fully fund development of the long-range anti-ship missile? And what is the capability as far as leaping ahead here?

Dr. PRABHAKAR. This was a project that DARPA began about 5 years ago in response to what we heard from the Pacific Fleet, basically their concern about being out-sticked, not having the range for anti-ship missile capabilities, particularly in the Pacific theater. We rapidly put together a program that culminated with successful flight tests for the DARPA stage of the research. Those flight tests were last fall. And the work that is now going on with DARPA's funding is in fact wrapped up for that program because we have successfully shown those flight tests.

What is happening now is a joint DARPA and Navy effort to try to get from that flight test to operational capability as rapidly as we can. Because it is an urgent known requirement for the Navy, it is something that we are hoping that the Navy will be able to get across the finish line very quickly.

Senator SHELBY. Ms. Miller, could you just for a moment, for the record here today, speak to the importance of providing adequate funding—and that is part of what this hearing is about—to field new weapon technologies like the Army's missile and rocket advanced technology, how important that is to the service that is down the road, the Army particularly?

Ms. MILLER. Obviously, I believe it is very important for the Army to have robust funding in our air and missile defense capabilities at AMRDEC (Aviation and Missile Research, Development, and Engineering Center) down in Huntsville, also PEO (Program Executive Office) Missiles and Space. We have a pretty solid program in the Army's science and technology portfolio. We have taken a slight dip in that particular technology area, but that is not a deliberate decision not to fund that. That was the completion of a successful program in our extended area protection system, a missile development capability. And so we have completed that. And as we go into the next 2015 through 2019, we start to pick up with counter UAS (unmanned aircraft systems) capability development.

Senator SHELBY. Could you also speak to the proposed high energy laser demonstrator and what this potentially could do?

Ms. MILLER. Absolutely. For the Army, the Space and Missile Defense Command is leading all research in high energy lasers. This is a capability that all of the services co-funded—the development of solid state laser capability under the High Energy Laser Joint Technology Office. And then each one of us has taken that capability and is demonstrating it in an operational context.

For the Army, we have been working out at WSMR (White Sands Missile Range) and doing some tests there. We have just recently gone with the Navy to test this at Eglin and see how the laser operates in that kind of environment because the Army pretty much is anywhere in the world and we need to make sure that it works in our capacity. It has been very successful against mortars and UAVs (unmanned aerial vehicle). It is slated to go into a program

of record, our integrated fire protection system, in the 2022 timeframe.

Senator SHELBY. Thank you, Mr. Chairman.

Senator DURBIN. Senator Collins.

Senator COLLINS. Thank you.

MALARIA VACCINES

Dr. Rauch, I agree with the chairman's observation about the important contributions the Department of Defense has made to medical research. Oftentimes we think of traumatic brain injury where the Department has played such an important role.

But the Department has gone beyond that and contributed in important ways in other areas such as infectious diseases. I was interested to read that the military infectious disease research program states that infectious diseases such as malaria historically cause more casualties when our troops are deployed to tropical regions than does enemy fire.

Could you give us an update on efforts by the Department of Defense to develop a vaccine that would be effective against malaria?

Dr. RAUCH. Yes, ma'am.

First of all, you are quite correct in that in the deployed force, there is a lot of morbidity associated with infectious diseases. Very true. And that is why we have an infectious disease research program that is dedicated to actually protecting our forces as they go into an endemic infectious disease area. Most concerning are infectious diseases such as malaria, dengue fever, and the diarrheal diseases. These are things that we really focus on.

VACCINE RESEARCH EFFORTS

With respect to malaria, we partner with the Gates Foundation and also with private industry to mature these products along. There is one product that was really developed and the preclinical work was done at Walter Reed Army Institute of Research. It came out of that tech base, was picked up then by GlaxoSmithKline. And those are phase III trials that are being conducted, and it is really showing about 50 percent efficacy in protection.

Now, you may say, oh, 50 percent. Can we do better than that? Malaria is a very, very challenging parasite. It is very agile. It is very flexible. You think you have it one time, and it changes. It is very agile. And so it is very much a challenge to come up with an efficacious medical countermeasure or vaccine. But those results from the phase III trial are very, very promising.

There is also a candidate that is coming out of the Navy lab that is also very promising. So partnering with NIH in this area shows a lot of Federal leverage to tackle this problem.

Senator COLLINS. Thank you.

Admiral Klunder, oftentimes it is small businesses that come up with the truly innovative products, and I can see Ms. Miller nodding in agreement as I say that. But it can be very difficult for a small business to comply with the cost of submitting a bid, with changing specifications, with rescoping of projects. And I want to give you an example from my home State.

SMALL BUSINESS OPPORTUNITIES

A small Maine shipyard built a prototype vessel for the Navy and for Special Forces and ultimately won a contract to build an advanced rescue craft for the military. And one of the challenges—the greatest challenge for this small business—was not building the high-tech vessel. It knew how to do that. But it was dealing with the expense of recurring costs associated with dealing with a very complex procurement process. What happened in this case is this small business submitted a bid at great cost to the business in response to the Navy's RFP (request for proposal) to supplement or replace the Mark V Special Operations Craft, only to watch the Navy change its mind, rescope the project, and publish a second new RFP. And for a big company, that would not be a problem. For a small company, it forced this firm to abandon the project due to the complexity, difficulty, and expense of completely redoing its bid.

So what has happened is the Navy has now lost a competitor for a project despite the fact that this small firm demonstrated in building a prototype that it could perform exactly the kind of work that the Navy wants.

So my question for you is how does the Navy ensure that you do not inadvertently exclude small businesses that do not have the kind of resources that a large defense contractor has to rebid on a contract when the Navy changes its mind.

Admiral KLUNDER. Thank you, Senator Collins.

I am not 100 percent involved in the details of that acquisition process, but I am familiar with it. And I offer two thoughts.

One is we absolutely love the innovation that comes out of small businesses. As a matter of fact, on the railgun system that I have down at Dahlgren we developed, 80 separate companies were involved in the development of that. That is big and small. So I promise you I love working with small businesses. As a matter of fact, in 3 weeks here in the beginning of June, we are having our Navy Opportunity Forum to address specifically small businesses, and that is here in DC. So I will reach out.

But on this specific company, because I do know about the issue at hand, I would like to offer that what I have done is, even though I know that process may have had some holes in it in terms of the complications and complexity you described, I have gone back and looked at that technology because there may be things we are going to do in the future, not necessarily a spec ops Mark V, but maybe connectors as we work with the Marine Corps, getting from sea to shore. I am looking at some of those technologies, I am going to reach out to that company, ma'am.

Senator COLLINS. Thank you.

Thank you, Mr. Chairman.

Senator DURBIN. Senator Murkowski.

Senator MURKOWSKI. Thank you, Mr. Chairman.

And thank you to all of you this morning. Very interesting.

I wanted to ask a couple questions here about HAARP, the High Frequency Active Auroral Research Program. Several of you at the table have a little bit of a piece here. As you know, this is located up in Alaska. It is currently funded by the Air Force research lab. It was formerly funded by the Office of Naval Research. One of the

prime customers is DARPA, which is currently running experiments at the facilities there. So questions to several of you this morning.

I am told by the president of the University of Alaska that the Air Force has pulled its support for the facility and they are taking steps to demolish it or take it down this summer. He is making the argument that there are other opportunities for us, and he is trying to find a path where the university might be able to take title to the facility.

I would like to start with you, Dr. Prabhakar. I understand that a lot of folks here on the committee probably do not understand what HAARP does. I think most Alaskans do not really know what HAARP does or why the agency is involved in it. So a very brief explanation and then a more direct question. Would you be disappointed or would you lose something if HAARP were to go away?

Dr. PRABHAKAR. Senator Murkowski, as I think you know, one of our programs has been using the HAARP facility for the research that it is pursuing, and my understanding is that we did get value out of that interaction.

The "P" in DARPA is projects, and we are not in the business of doing the same thing forever. So very naturally as we conclude that work, we are going to move on to other topics. So it is not an ongoing need for DARPA despite the fact that we had actually gotten some good value out of that infrastructure in the past.

Senator MURKOWSKI. Understood.

Then to Dr. Walker and Mr. Shaffer—Dr. Walker, your agency is currently running the facility. I have mentioned that it is our understanding through the president of UAF that the plans are to move forward and demolish the facility this summer. So the question to you is, is that accurate? Can you explain why?

And then perhaps to both you and Mr. Shaffer, is there any benefit in exploring a potential relationship with the University of Alaska to perhaps take over the HAARP?

Dr. WALKER. Thank you, Senator.

The Air Force has gotten great value out of HAARP in the past. We took it over from the Navy and managed it and actually did a number of experiment campaigns up there and have finished our work that we are interested in doing up there. We are moving on to other ways of managing the ionosphere, which the HAARP was really designed to do, was to inject energy into the ionosphere to be able to actually control it. But that work has been completed.

The Air Force has maintained the site for other Government agencies to use for several years now, and with DARPA completing their project, that is our last Government customer that we have in the site.

We have put out a call Governmentwide for other agencies that had interest in managing the site or taking it over, including going out to academia and seeing if there was an interest there. And we have gotten interest from the university in Fairbanks. However, the interest that we have is that they will run it if we fund it, which is unfortunately in this fiscal environment we are in right now, this is not an area that we have any need for in the future and do not see that it would be a good use of Air Force S&T funds in the future. So our position has been that if there is not some-

body who wants to take over the management and the funding of the site, then the Air Force has no future need, and that we do plan to do a dismantle of the system in the future after we make appropriate notifications.

Senator MURKOWSKI. When you say in the future, do you anticipate that it would be this summer then? Or would there perhaps be more time for the university to try to figure something out?

Dr. WALKER. We would prefer to start this summer. We would like to get the critical equipment out of the site before the winter. The harsh winter in Alaska does lead to a very costly winterization to maintain the site, and we would like to avoid that if we can.

Senator MURKOWSKI. Mr. Shaffer, if you have any comments on that.

Mr. SHAFFER. Yes, ma'am.

So I am torn on this because my background is as an atmospheric scientist, and I think the facility is just a world-class facility.

That said, we have worked very hard with the Air Force, with the Office of Science and Technology Policy over the last 18 to 24 months to find another sponsor for this because, as you have heard the other people at the table, we, the Department, have gotten the research value out that we need for the facility. We have also worked with the University of Alaska Fairbanks to get some other person to pick up the long-term, just pure scientific research that HAARP offers the promise of. But with all the other issues and problems and challenges facing the Department at this time, we just do not see that that investment over a long-term period is where we would prioritize our investments.

So we have been working with other agencies, trying to get agencies like the National Science Foundation, Department of Commerce who runs the National Ocean and Atmospheric Administration, to pick up the HAARP facility. No one else wants to step up to the bill, ma'am.

Senator MURKOWSKI. Let me ask you one final question here, Mr. Shaffer, and this is regarding small modular reactors. In the report language with the National Defense Authorization Act last year, DOD was directed to carry out an assessment of small modular reactors of 10 megawatts or less. As energy sources for our forward operations, I have always thought that this made a lot of sense, particularly in some of our remote areas. We have got Eielson Air Force Base up north that could clearly benefit from a reliable energy security that nuclear power could provide. But you need it on that smaller scale.

Are you considering such domestic deployment operations for SMRs?

Mr. SHAFFER. We have been in discussion with the folks who are selling that particular technology. What we cannot get over, ma'am, is the sticker shock. There are a lot of other issues, but the sticker shock of the initial investment. So by the time you would do environmental impact statements and all the rest, even to put in a small nuclear reactor, every time I have looked at it, the bill has been around $1 billion. That is a lot of money in the current fiscal environment.

I think I would speak for everybody at the table. As technologists, we think the technology offers tremendous promise, but getting past all the regulatory and all the other things that would constrict us to putting in a new nuclear reactor just makes it a very, very hard thing to work our way through.

I was in Eielson last summer. I understand exactly the need for that type of capability, but we will need some help. And frankly, it is kind of the Department of Energy's ball to carry in many ways.

Senator MURKOWSKI. Well, and it is something that I think many of us are involved with here, trying to figure out how you can expedite that permitting process, how we can work to reduce those costs. But you are correct. We are probably still a ways away. I appreciate your perspective on it.

Thank you, Mr. Chairman.

Senator DURBIN. Thanks, Senator.

The last question, I know I asked too many for a short period of time, was about the coordination of different agencies in areas like biomedical research. It is my understanding that the NIH and DARPA and others are doing the BRAIN Initiative. What I am trying to get is some assurance, and I think I am going to get it that at the outset, there is a coordination of effort and resources so that we do not waste any time or money.

Dr. PRABHAKAR. Yes. Sorry. Let me just speak specifically to the BRAIN Initiative, and then, Terry, please dive in.

Absolutely, yes. We have had a lot of very good dialogue with NSF and NIH in particular on the BRAIN Initiative.

Here is how we think about it, if this is useful to you. NSF and particularly NIH have built this phenomenal research foundation through the investments that they have made in biomedical research over many, many years. What we want to do at DARPA and our programs are doing today is building real technology capabilities out of some specific areas of new insights in brain function research. And it is a very good interplay. Our investment is very small compared to the neuroscience investment over many decades at NIH, but I think it is a time when there is a huge opportunity to build real technical capability.

Senator DURBIN. Is the same thing true of other areas in our appropriations bill where we are kind of specifying a line item different areas of medical research? Can the same be said, Dr. Rauch?

Mr. SHAFFER. Senator, let me take this and then I will let Terry talk about his specific area.

We have been concerned for a number of years about better coordination of the programs. As you see here, we have three services, a number of agencies doing research in every area. Over the last 18 months, we have put in place a structure that took the best of what we had previously to coordinate our activity in 17 areas. That process is called Reliance 21, Communities of Interest. So in 17 areas where multiple agencies have an investment, we have the senior executive or senior leader who is responsible for investment of money coordinate their program with the other components because everybody wants to get the maximum out of their ability.

One of these 17 areas—we actually adopted a body that was there before called ASBREM (Armed Services Biomedical Research

Evaluation and Management), and I will turn it over to Terry because Terry is one of the co-chairs of ASBREM with my director for biomedical sciences. They actually do the coordination of the biomedical research area.

Terry.

Senator DURBIN. I want to thank you for a new acronym.

Go ahead.

BIOMEDICAL RESEARCH, EVALUATION, AND MANAGEMENT

Dr. RAUCH. Well, sir, it is not a new acronym. It has been around for a while, but we continue to refine it.

The ASBREM is really a mechanism to assure coordination across the Department. It is one mechanism to assure coordination of medical research across the Department. We actually have a liaison officer from Health Affairs that is actually assigned over to DARPA to make sure that DARPA and DHP programs are coordinated. I mean, that is an investment on our part.

You know, the National Research Action Plan really sets the foundation particularly in the area of mental health research to assure coordination. There is hardly a day that goes by that I am not talking or emailing with my colleague over at the VA, Tim O'Leary, or with Tom Insel at NIH or his staff about the different projects that we have ongoing in mental health research.

Every year for the last 4 years, we have held joint portfolio R&As, review and analyses, where the DOD program is presented in combat casualty care research and TBI and psych health research and infectious diseases and operational medicine and rehabilitation. The VA presents their program at the R&A. The NIH presents their program at the R&A. It is fully transparent. It enables us to see in a coordinated fashion the state of science that we are funding with our Federal dollars. And it enables us to determine where the gaps are, Federal gaps, and how we can correct those gaps or invest in those gaps. It informs our next upcoming investments.

One last thing, sir, and I have to make a point. What comes out of these, in addition to what comes out of these portfolio reviews, is joint initiatives. Last year, the DOD and the VA co-funded two major consortia, one for PTSD and one for traumatic brain injury. When I say co-funded, I mean the VA put up their intramural program dollars that went to the awardee on the VA side, and we put up DHP (Defense Health Program) R&D dollars that went to the awardee on the academic side. Their consortia is at the University of Texas Health Science Center in San Antonio. That is the one for PTSD. The co-investigator is Terry Keane up at Boston VA. The one for traumatic brain injury is David Sifu down at VCU (Virginia Commonwealth University) who also has an appointment with the VA in Richmond. These are 5-year consortia, a 5-year period of performance. The first time we have ever done this together with the VA.

We do something very similar with NIDA (National Institute on Drug Abuse) in terms of putting out joint program announcements where DOD will fund research on drug abuse, as well as NIDA.

So we cost share. You can see that in combat casualty. I mean, I can go on and on and on.

Senator DURBIN. Thank you for that.

Dr. RAUCH. Your time is precious.

Senator DURBIN. Thank you.

Do any of my colleagues have any follow-up questions? Senator Shelby.

Senator SHELBY. I have a couple of questions for Admiral Klunder.

HIGH-POWER DENSITY WATER JET DEVELOPMENT

Admiral, in the area of Office of Naval Research, it is my understanding that ONR delivered a new high-power density water jets to the Freedom variant of a littoral combat ship, LCS. Could you please provide an update of that testing, and what that will do?

Admiral KLUNDER. Yes, Senator, thank you.

And again, I offer that that work was done from a consortium of larger and small businesses. So that is very important to us.

Senator SHELBY. Why is it important to you?

Admiral KLUNDER. We feel that if we are going to stimulate the economy and the industrial base——

Senator SHELBY. No. I mean why the water jet——

Admiral KLUNDER. Oh, the water jet, certainly. Well, not only the ship itself but the fuel efficiency that we derive was incredibly impressive. We are not talking about one or two extra percentages. We are talking almost around 10 percent of fuel efficiencies we get out of this water jet. And again, I am a physicist. So there is a little bit of flow dynamics. But the point is we were able to test that, fabricate it with help in your great State. And then when we implemented that on the ship, it is now working.

I would offer manufacturing, industrial base. We have a problem. How can we make it better, more fuel efficient? We injected with the industrial partners—performers and we will deliver that I think in a reasonably fair amount of time, which is on our ships now.

JOINT HIGH SPEED VESSEL RAMP DEVELOPMENT

Senator SHELBY. This came about, as you mentioned, by some broad research working with others. Right? And businesses.

Admiral KLUNDER. Yes, sir. And again, I think that was a great partnership from funding from ONR but also with local businesses.

Senator SHELBY. In another area, the joint high speed vessel ramp you are familiar with the Office of Naval Research completed a demonstration of a new lightweight ramp for the Navy's joint high speed vessel earlier this month. Could you discuss that and how you are going to implement this? And what will it do for you—do for us?

Admiral KLUNDER. Sure. And again, I think for those that are not familiar with the joint high speed vessel, this is a very affordable, high speed vessel. It has lots of modular space in it. And why do I emphasize that? Because that vessel can now be used for multiple, multiple missions. We could use it to connect marines to go inland. We could use it potentially to put other kind of systems on there that may be spur of the moment, new threats as they come about.

But to do that and to make sure it is truly multimission, we needed it to have a very effective ramp. And that ramp has been tested quite well. As I represent not only the Navy but the Marine Corps, the Marine Corps is very interested in that ramp and how it may be implemented on JHSV or other modular ships we are building as MLP. I think you are familiar with that ship also, Senator.

JOINT HIGH SPEED VESSEL ATTRIBUTES

Senator SHELBY. Admiral, can you explain briefly what the joint high speed vessel will mean for us in the Navy?

Admiral KLUNDER. Thank you, Senator.

Well, not only will it be a ship that can move very fast and very efficient on fuel, but again, it can carry a number of marines. It could actually put potentially a new weapons system——

Senator SHELBY. And be heavily armed too, could it not?

Admiral KLUNDER. Yes, sir.

And we can put it anywhere in the world quite quickly.

Right now we have built—there is a number of those through the acquisition process that are being built and fielded. And as a matter of fact, this July we are going to bring one into San Diego and put the railgun on it to show the public.

What I think really is important, as we continue to work with this ship and figure out different missions, it can really be used around the globe. It is not particular to one part of the globe. We could put it anywhere in the world and that is really part of its——

Senator SHELBY. So the Navy and Marine Corps are very pleased with what——

Admiral KLUNDER. I would say we are fully embracing it, Senator. Thank you.

Senator SHELBY. Thank you.

Admiral KLUNDER. Yes, sir.

Senator COCHRAN. Mr. Chairman, could I ask unanimous consent to submit two questions to Dr. Walker and Admiral Klunder for the record?

Senator DURBIN. Without objection.

Senator Murkowski.

ARCTIC SENSOR DEVELOPMENT

Senator MURKOWSKI. Mr. Chairman, very briefly. I know we have got a vote that has just started.

But I wanted to just bring up very quickly with you, Dr. Prabhakar, I have mentioned, as cabinet members have come before different panels before us, my interest in making sure that this administration is advancing our national interests in the Arctic. And I have been somewhat disappointed with some lackluster implementation plans, but I have been very encouraged by DARPA's Assured Arctic Awareness initiative. I know that you have got some data that is coming back that you have been collecting out in the region. I am hoping that you are getting some early indication of good value coming out of that and, again, that you are really committed in moving forward in this initiative that I think is critically important not just for the State of Alaska, not at all, but truly for the entire Nation. So, first of all, I thank you

for what DARPA is doing, but I would just encourage you to push a little harder on it.

Dr. PRABHAKAR. Thank you very much for the comment, Senator Murkowski. And you are right. This is a national issue. The Navy has got its hands full with the oceans that we already know and a whole new ocean is appearing before our eyes in the Arctic, and the conditions there are very interesting, dynamic, and challenging. I too am looking forward to seeing what we are going to learn from our initiative.

Senator MURKOWSKI. Do you know when that might be coming out?

Dr. PRABHAKAR. I know that we are still in the process of getting the data back.

ADDITIONAL COMMITTEE QUESTIONS

Senator MURKOWSKI. I will look forward to——

Dr. PRABHAKAR. Yes, same here.

Senator MURKOWSKI [continuing]. Having some collaboration on that. Thank you.

Admiral KLUNDER. Senator, could I just—since I am in the Navy and the Arctic means a lot to us. And thank you, working with DARPA. I am not sure if we are all aware of it. Just this March we put another level of sensors off the Beaufort Sea off your great coast, and that was done in March. And we are going to measure that summer retreat of the marginal sea ice, and we are actually going to come up to Deadhorse Bay and Prudhoe Bay here in July to add some more sea gliders and wave gliders to complement that exercise.

Senator MURKOWSKI. Great.

Admiral KLUNDER. So we are doing a fair amount of research and development up there to truly understand the environment because we think it is so important, Senator.

Senator MURKOWSKI. We appreciate that. Thank you, Admiral.

Senator DURBIN. Thank you, Senator Murkowski.

[The following questions were not asked at the hearing, but were submitted to the Department for response subsequent to the hearing:]

QUESTIONS SUBMITTED TO ALAN SHAFFER

QUESTIONS SUBMITTED BY SENATOR DANIEL COATS

Question. Naval Surface Warfare Center (NSWC) Crane has become widely recognized across the Department of Defense, and within the Federal Lab System for rethinking and pioneering Technology Transfer. Currently, the Research Directorate within Assistant Secretary of Defense—Research & Engineering (ASD–R&E) and the State of Indiana are collaborating around Crane's successes to demonstrate how a lab's innovation can be used to increase the lab's mission effectiveness. Is this model something that can be shared and exported?

Answer. Yes. Leadership of NSWC Crane designated Technology Transfer (T2) as a command priority in 2005 and invested in their Office of Research & Technology Applications (ORTA), the group responsible for leading and implementing the local T2 program. Crane's ORTA, recognized as one of the best within the Department of Defense, initiated a strategic effort to work as appropriate with Indiana's academic and business communities as well as local and state government organizations. The best example of T2 success is found in the creation of the Battery Innovation Center located near NSWC Crane. This is a nexus for new power technologies needed by the military while concurrently developing products for the commercial marketplace.

Question. Are there any future structure changes required and strategy alterations to leverage what has been demonstrated in Indiana?

Answer. Congress has provided all of the needed authorities for an effective Department of Defense Technology Transfer (T2) Program; no additional authorities are required at this time. A number of Defense laboratories, with support from the Assistant Secretary of Defense (Research and Engineering) (ASD(R&E)) Defense Laboratories Office, have accelerated their local T2 programs.

Question. What is DOD's strategy for leveraging intellectual capital for enhanced mission effectiveness and economic development?

Answer. The ASD(R&E) Defense Laboratories Office participates in the White House Office of Science & Technology Policy (OSTP) Lab-to-Market initiative as well as the Federal Laboratory Consortium (FLC) to broaden the government-academia-industry T2 network. Lessons learned and opportunities for DOD's labs to participate in a national T2 environment are promulgated to the Defense labs' ORTAs for consideration and implementation. A T2 guidebook has been written and distributed to the defense labs. When ASD(R&E) learns of other laboratory's T2 successes, the experiences and processes are shared across the entire Department lab system.

QUESTIONS SUBMITTED TO DR. ARATI PRABHAKAR

QUESTIONS SUBMITTED BY SENATOR DIANNE FEINSTEIN

Question. Is DARPA planning to continue development of robotic arms and associated robotics capabilities for the advancement of in-space satellite servicing and to conduct an in-orbit demonstration of these capabilities?

Answer. Yes. DARPA recognizes the strategic importance and the commercial potential of in-space satellite servicing and is developing the required capabilities on a priority basis. DARPA is developing robotic arms and associated robotics capabilities developed under DARPA's Phoenix program into an in-orbit demonstration program with multiple capabilities. The in-orbit program will validate capabilities in geostationary earth orbit of high strategic importance for new Department of Defense (DOD) concepts as well as high commercial potential (e.g., satellite inspection, repair, and in-orbit assembly). The multimission demonstration spacecraft would be designed for an extended mission lifetime, enabling follow-on operations by a commercial space contractor after successful completion of a test and demonstration phase by DOD.

Question. Is DARPA planning to continue the advancement of the "Payload Orbital Delivery System" and to demonstrate this capability?

Answer. Yes. MacDonald Dettwiler and Associates and Space Systems Loral are currently under contract to continue engineering and integration planning in order to deliver a flight-qualified unit to host a Payload Orbital Delivery (POD) System on a commercial satellite. This capability will provide an alternative low-cost and high-tempo delivery of mass to geostationary orbit for DOD. During the ongoing technical development of the flight hardware, DARPA will continue to evaluate future opportunities to host and fly the POD concept on a commercial satellite.

Question. Without having a DOD office for satellite servicing, what approaches is DARPA considering for the transition of these critical capabilities to ensure their availability to our DOD stakeholders?

Answer. DARPA embraces opportunities for transition. While transition is most directly accomplished through the Services, it can also be accomplished by advancing the technologies through our performers. Proof of the technology coupled with the push to industry often results in benefits to the DOD in the future.

QUESTIONS SUBMITTED BY SENATOR DANIEL COATS

Question. With the growth of emerging threats to the microelectronics supply chain, some of which have recently been discovered by NSWC Crane, what is DARPA doing to ensure that its advanced technical assessment capability such as the DARPA IRIS (Integrity and Reliability of Integrated Circuits) Program is being transitioned to labs such as Crane?

Answer. In order to ensure that the advanced technical counterfeit component mitigation capabilities developed at DARPA are transitioned to the most effective labs at the completion of these programs, DARPA engages likely transition partners as government team members during their actual execution. Personnel from the transition partners, including Crane, actively work on this program, even to the point of having badge access to the DARPA facility. In this way, critical informed

feedback and required application boundary conditions may be incorporated into the required deliverables from the outset of the program.

In the case of NSWC Crane, the Indiana lab's hardware assurance team is widely recognized as a national center of expertise, one of the only two or three true centers of competence in the country for mitigating threats to DOD's supply chain. DARPA MTO and its program managers involved in hardware assurance are fortunate to have access to the experience and insight which NSWC Crane, Indiana brings to the programs it helps support. Specifically, Brett Hamilton, an expert in anti-counterfeit technology from Crane, is intimately involved in the program, has DARPA badge access, and works hand in hand with the program manager in execution of the program. The technology developed by DARPA performers is frequently transitioned to Crane. Examples include chip imaging techniques for electrically probing and visualizing the behavior of unknown circuits.

Question. NSWC Crane is part of a "Virtual Lab" consortium providing support to DARPA's IRIS (Integrity and Reliability of Integrated Circuits) Program. What are the benefits to this type of arrangement? How can this "Virtual Lab" be leveraged to provide a more proactive approach to dealing with emerging threats to microelectronics and the supply chain? Do you have any plans to visit NSWC Crane?

Answer. The "Virtual Lab" concept conceived by DARPA in collaboration with government sponsors benefits the Nation and its hardware assurance research by leveraging the unique, powerful know-how that each lab such as NSWC Crane, Indiana has developed. By offering these skills under the support of a single organization, the practice of multiple critical capabilities is drawn into a single community. Providing a unified access to these centers of competence allows the community to focus on extending its prowess and eliminating costly duplication of effort. The equipment is highly specialized and therefore impossible to replicate across the country everywhere it would be needed. By forming the virtual organization, we are able to multiply the impact of the transition of each of these outputs.

The Virtual Lab will continue to be leveraged, as the Senator indicates, by proactively anticipating new threat space and developing the means to detect and mitigate these new concerns. Core competencies transitioned to lead Virtual Lab partners such as Crane will continue to be used to detect and collect counterfeit components for study, identifying new modes of hardware compromise being attempted. Examples of items transitioned include powerful laser-based imaging capabilities which allow the community to reveal electronic device characteristics which up to now were not accessible for reverse engineering.

DARPA's program manager for assuring hardware integrity visits NSWC Crane often, and briefs his agency leadership on emerging trends and the prowess we have responded with. The critical work for this program is performed as a close engagement between the program manager and the engineers at Crane. DARPA also hosted a DARPA young faculty awardee meeting at Crane where faculty and designers from across the country came to see their facilities including the anti-counterfeit related work. The Director of the Microsystems Technology Office, which runs the TRUST, IRIS and SHIELD programs is on loan from Purdue University as an IPA and gets back to Indiana regularly to meet with current and former students, many of which are at NSWC Crane.

QUESTIONS SUBMITTED TO DR. DAVID WALKER

QUESTIONS SUBMITTED BY SENATOR MARK L. PRYOR

Question. Congress included language in the Fiscal Year 2014 Defense Appropriations Report encouraging the Air Force to invest in next generation free space optical communications technologies for secure, high-speed and high-bandwidth data transfer. How does the Air Force plan to develop and demonstrate free space optical communication technology for applications such as UAV-to-ground and other air-to-ground and air-to-air applications?

Answer. The Air Force must exploit emerging technologies to improve our ability to transmit the ever-increasing volume of Intelligence, Surveillance and Reconnaissance data for processing, exploitation, and dissemination. However, the fiscal constraints directed by the Budget Control Act of 2013 limits our ability to invest in free space optical communication technologies. The Air Force will continue to seek opportunities for investment in promising technologies that will enable us to maintain a decisive advantage in air, space and cyberspace.

Question. Recently, a Small Business Innovation Research (SBIR) award was made concerning free space optical communication technology by the Air Force. What is needed beyond the SBIR to advance this capability?

Answer. The SBIR is focused on free space optical communications systems suited to fixed, geostationary satellite-to-ground and building-to-building terrestrial communications capabilities. Further development is needed to reduce the size, weight, and power of these systems, particularly for remotely piloted aircraft (RPA) applications. Utilizing free space optical communications for air-to-air links requires a higher fidelity pointing, acquisition, tracking system. Further research is also needed to expand the capabilities of current point-to-point apertures to support multiple, simultaneous links for networked configurations from a single aperture. Finally, single-aperture, adaptive beam control is required to support dynamic aerial mission execution at rapid, tactical operations tempos. The SBIR will demonstrate a basic laser communications link suitable for static applications, but these additional technology advancements are required in order to support highly dynamic missions such as those conducted by RPAs.

QUESTION SUBMITTED BY SENATOR DANIEL COATS

Question. Naval Surface Warfare Center Crane is the largest multiservice, multidomain facility within the Department of Defense (DOD) for Electronic Warfare (EW), EW sensors and electronics. What plans does the Air Force's Science & Technology program have in fiscal year 2015 to partner with NSWC Crane in the area of electronic warfare to maximize the limited amount of EW resources? Do you have any plans to visit NSWC Crane in the near future?

Answer. The Air Force Science and Technology program has a strong and ongoing relationship with various elements at Naval Surface Warfare Center Crane (NSWC–Crane). Both establishments recognize the importance of collaboration in order to avoid duplication, to make efficient use of funding, and to leverage the technology advancements each organization develops.

The Air Force Science and Technology program encompass four main areas of aircraft protections: Radio Frequency Electronic Warfare (RF–EW); Electro-Optical/Infrared Countermeasure (EO/IRCM); Avionics Vulnerability Assessments, Mitigations and Protections (AVAMP); and Position, Navigation and Timing in Contested/Denied Environments.

The Air Force Science and Technology program interacts with NSWC–Crane in three areas: RF–EW, EO/IRCM and AVAMP.

In the area of RF–EW, The Air Force and NSWC–Crane have worked together on the Airborne Electronic Attack Analysis of Alternatives, maturation of Next-Generation Jammer technology, and collaborative development of the early generation of Digital Radio Frequency Memory (DRFM) cards used for EW.

This collaboration is continuing in several forms today beginning with miniaturized DRFM cards. For fiscal year 2015 NSWC–Crane will fabricate these cards for Air Force to support ongoing research in electronic attack and electronic support areas.

Cognitive EW is a growing interest area for the Air Force as we address modern air defense threats that are software defined and adaptive. The Air Force recently hosted a 6-month study on Cognitive EW in Anti–Access/Area Denied (A2/AD) environments. NSWC–Crane (along with other services) was a partner in this study to help develop a roadmap for future research activities. Further, NSWC–Crane has invited the Air Force to participate in the upcoming January 15, 2015 kick-off of their Reactive Electronic Attack Measures (REAM) FNC project.

The Air Force and NSWC–Crane also partner on DARPA activities. DARPA's Retroactive Array for Coherent Transmission (ReACT) awards are jointly managed by Crane and the Air Force while the Adaptive Radar Countermeasure (ARC) program is managed by the Air Force with NSWC–Crane providing SME support

Future plans for collaboration include NSWC–Crane support for distributed EW development and Air Force SME support to evaluate and assess Next Generation Jammer technologies. Bottom line is that the Air Force and NSWC–Crane RF EW collaborations are synchronized and mutually supportive.

Within the EO/IRCM area the Air Force has a number of ongoing collaborative efforts with NSWC–Crane beginning with their NICKEL Lab. The Air Force counterpart is the Dynamic Infrared Missile Evaluation (DIME) facility. The purpose of these facilities is to characterize various EO/IR threats. The Air Force's EO/IRCM collaboration with Crane has a rich history and is one that will only increase in the future especially as EO/IR weapon systems become more advanced and capable.

The strongest collaborative effort within AVAMP is in the area of Anti-Tamper which has been ongoing since the inception of the Secretary of Defense's Anti-Tamper program. Anti-Tamper technology protects U.S. critical information resident on weapons systems from loss due to combat losses.

QUESTION SUBMITTED TO REAR ADMIRAL MATTHEW L. KLUNDER

QUESTION SUBMITTED BY SENATOR DANIEL COATS

Question. Naval Surface Warfare Center (NSWC) Crane has become widely recognized across the Department of Defense, and within the Federal Lab System for rethinking and pioneering Technology Transfer. Currently, the Research Directorate within Assistant Secretary of Defense—Research & Engineering (ASD–R&E) and the State of Indiana are collaborating around Crane's successes to demonstrate how a lab's innovation can be used to increase the lab's mission effectiveness. What future role do you see for the Navy's Warfare Centers for both innovation and economic development? Do you see a leadership role for the Office of Naval Research and/or the Naval Research Laboratory in this process as the Navy's premier Research and Development organizations?

Answer. The Chief of Naval Research coordinates thousands of partnerships across the Department of the Navy's Research Enterprise which includes the naval warfare centers and the naval systems commands. These efforts are aligned with the nine focus areas of the naval Science and Technology strategy. Where appropriate, the field activities, including the warfare and system centers, team on technology transfer initiatives. The primary mission of these activities is to support the naval community with materiel solutions. Each R&D activity has a technology transfer office that stimulates economic benefit through technology transfer and cooperative development. Not only do the nature of the NSWC Crane's intellectual property and products set the stage for greater-than-average technology transfer opportunities, they have developed methods that are looked at as best practices across the Naval Enterprise.

QUESTIONS SUBMITTED TO MARY MILLER

QUESTIONS SUBMITTED BY SENATOR MARK L. PRYOR

Question. Congress is very supportive of research work at the Department of Defense and the Department of Energy to develop silicon carbide wide band gap power electronics and has provided funding to the Army specifically to increase Manufacturing Readiness Levels for silicon carbide power electronics and support domestic supply chain development. What is the Army's "roadmap" or plan for transitioning silicon carbide power electronics into Army systems?

Answer. With the addition of the referenced congressional silicon carbide special interest funding, the Army's silicon carbide starting material, power devices, and power packaging programs have been moving the technology toward commercial and custom power devices with higher efficiency, greater reliability, and lower cost. The resulting power devices and power module technology are being transitioned to 6.3 (Advanced) Technology Development demonstration programs sanctioned by Program Executive Office Ground Combat Systems with the end goal of transitioning the technology to combat vehicle programs of record. These programs are focusing on power generation, power distribution, and electrified propulsion systems implemented with silicon carbide power devices rated at the lower voltage range of 1.2 to 3.3 kV and vehicle survivability systems such as electro-magnetic armor implemented using silicon carbide devices rated at 15 kV. Technology Readiness Level 5/6 demonstrations are planned for fiscal year 2016 to fiscal year 2019 through the Combat Vehicle Prototyping Program with transition to Paladin Integrated Management Program in fiscal year 2016, the Future Fighting Vehicle in fiscal year 2021, and Stryker and Bradley Modernization Programs in fiscal year 2022.

Question. How will the Army allocate and execute silicon carbide research funds appropriated in fiscal year 2014 taking into account the better outlook for technology transition and domestic supply chain development for low voltage applications?

Answer. In fiscal year 2013, an additional $13 million was added by Congress for silicon carbide research. Of this $7.6 million and $3.1 million was used to increase Manufacturing Readiness Levels (MRL) for starting material, power devices, and power packaging rated at the lower voltages (1.2–3.3 kV) for power generation, power distribution, and electrified propulsion systems and at the higher voltages

(10–24 kV) for electronic survivability systems, respectively. With the referenced fiscal year 2014 funding of $10 million, the Army plans to apportion the research similarly with about $7 million funding power electronics rated at lower voltage and about $3 million funding the higher voltage applications. With the fiscal year 2013 special interest funds we started efforts with two external partners (United Silicon Carbide Inc. and Monolith Semiconductor Inc.) that are using fully depreciated 6" diameter silicon foundries for fabrication of their silicon carbide power device designs to take advantage of highly cost-effective excess silicon processing capability. Further, with the fiscal year 2013 funds we refocused work at a current partner (Arkansas Power Electronics Inc.) to include power packaging technologies for high-temperature silicon carbide power devices rated at the lower voltage range (1.2– 3.3 kV). We will continue efforts with these external partners using the fiscal year 2014 special interest funding as well as add at least two new external partners to further increase MRL levels and broaden the tech base of the supply chain. The Army will continue to coordinate with the Department of Energy to ensure that both agencies' programs with common external partners are leveraged to provide maximum benefit to the government.

QUESTION SUBMITTED BY SENATOR SUSAN M. COLLINS

Question. The University of Maine has developed a "bridge in a backpack" for constructing short- to medium-length bridges in the field with very light-weight materials. Soldiers or Marines can literally carry the materials needed to build a bridge on their backs without having to use heavy equipment or large crews.

What research is the Army conducting to reduce the logistics footprint necessary to conduct expeditionary operations, from small items to larger infrastructure such as bridges?

Answer. Army Science & Technology has a wide variety of research efforts that aim to reduce the Army's logistics footprint. A few examples include Modular Protection Systems which provide easily assembled, rapidly deployed force protection in austere environments; virtual contingency base planning tools which reduce operations, support, and resupply costs; and highly efficient field waste water systems that reduce potable water demand and waste water production at contingency bases.

Many of our efforts in reducing our logistical footprint are underpinned by advanced materials science research, a high priority initiative in Army Basic Research. The Army's Materials by Design within the advanced materials science research initiative is a paradigm shift for the development of new classes of materials. This could result in greatly reduced weight for protection materials, much higher energy density for batteries, and more efficient, longer lasting electrical components.

QUESTION SUBMITTED BY SENATOR DANIEL COATS

Question. Naval Surface Warfare Center Crane is the largest multiservice, multi-domain facility within the Department of Defense (DOD) for Electronic Warfare (EW), EW sensors and electronics. What plans does the Army's Science & Technology program have in fiscal year 2015 to partner with NSWC Crane in the area of electronic warfare to maximize the limited amount of EW resources? Do you have any plans to visit NSWC Crane in the near future?

Answer. The Army Science and Technology community has partnered with Naval Surface Warfare Center (NSWC) Crane on a number of initiatives. For instance, the Army's Communication Electronics Research and Development Center, Intelligence and Information Warfare Directorate (CERDEC I2WD) supports joint Service working groups developing defensive electronic attack techniques and standardizing seeker countermeasure lab practices across the Services. Additionally, NSWC Crane created the Communications Electronic Attack with Surveillance and Reconnaissance/Networked Electronic Warfare Remotely Operated airborne jammer pods for the Army. These systems have been retired from the field and CERDEC I2WD will be receiving one of the pods for experimentation. Finally, the Army Research Laboratory (ARL) held an information exchange meeting with NSWC Crane in fiscal year 2014, which included a discussion about sharing EW signature data. Crane has been extremely helpful to ARL, loaning a Counter Radio-Controlled Improvised Explosive Device Electronic Warfare Vehicle Receiver/Jammer and a Thor dismounted manpack jammer for compatibility experiments. ARL plans to continue to work with NSWC Crane during fiscal year 2015.

While I do not currently have plans to visit NSWC Crane, I would welcome the opportunity to do so in the future.

SUBCOMMITTEE RECESS

Senator DURBIN. Thank you to our panel for the testimony today. We are going to pursue this topic at the next level which is called appropriations. So we will try to help. Thank you very much for being here.

[Whereupon, at 11:21 a.m., Wednesday, May 14, the subcommittee was recessed, to reconvene subject to the call of the Chair.]